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Annual Report

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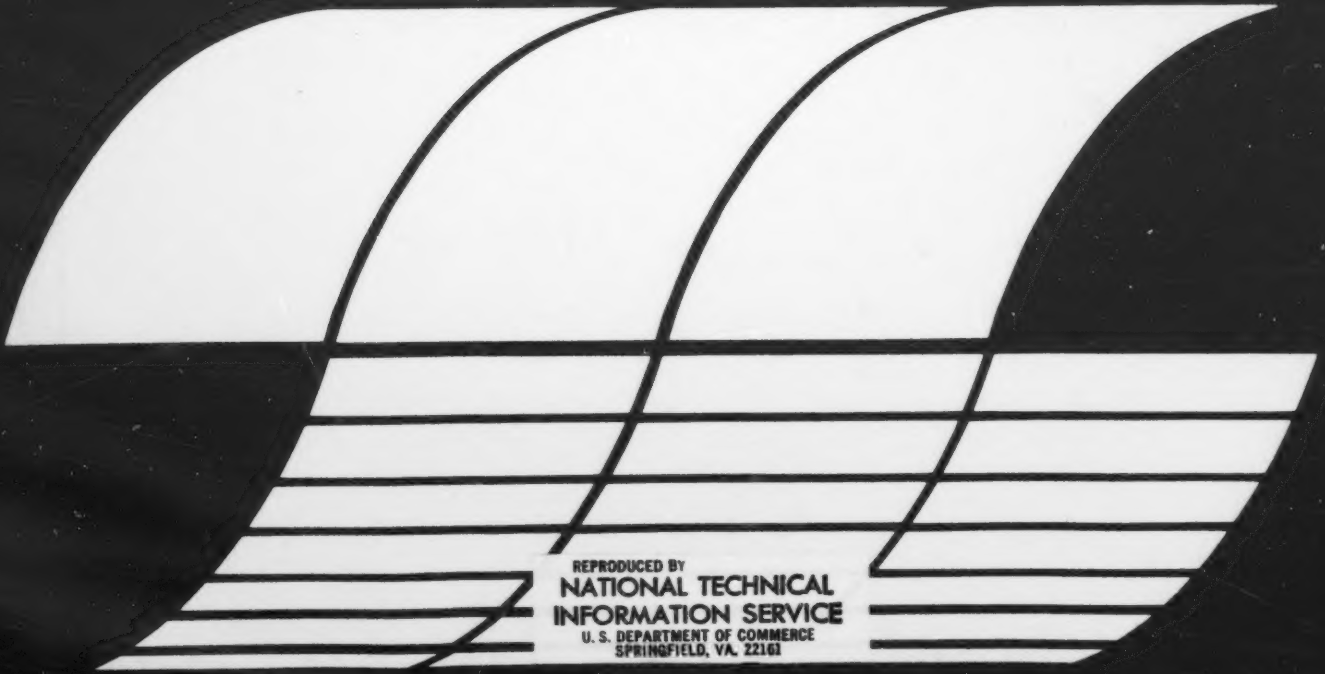

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The report summarizes results of a study of the environmental aspects of 14 of the most prominent coal liquefaction systems, in terms of background, process description, major operations, input and output streams, status, and schedule of system development. As a result of the study, four systems--SRC, H-Coal, Exxon Donor Solvent, and Synthoil--were selected for in-depth study. The first Standards of Practice Manual, under preparation for the SRC-I system, will include descriptions of modules, control/disposal practices, environmental emissions, and control/disposal costs.

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Prepared for

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ABSTRACT

Fourteen of the most prominent coal liquefaction systems have been studied in terms of background, process description, major operations, input and output streams, status, and schedule of system development. Four systems - SRC, H-Coal, Exxon Donor Solvent, and Synthoil - have been selected for indepth study. The first Standards of Practice Manual is under preparation for the SRC-I system which will include descriptions of modules, control/disposal practices, environmental emissions, and control/disposal costs.

Must of the information presented in this report represents work that is still in progress. As a result, the information is preliminary and should be used only as an indication of what is to come in future publications.

TABLE OF CONTENTS

Page

Abstract.................................... *ii*

Table of Contents........................... *iii*

List of Tables.............................. *viii*

List of Figures............................. *ix*

ACKNOWLEDGEMENTS............................ *x*

INTRODUCTION................................ *xi*

MANAGEMENT SUMMARY.......................... *xii*

A. Current Technology Background.................. 1
  1. System Information......................... 2
    a. Catalytic Liquid Phase Hydrogenation... 2
      (1) Synthoil System.................. 2
      (2) H-Coal System.................... 4
      (3) Bergius System................... 6
    b. Noncatalytic Liquid Phase Hydrogenation 7
      (1) Solvent Refined Coal System....... 7
      (2) COSTEAM System................... 10
    c. Pyrolysis and Hydrocarbonization....... 11
      (1) Char-Oil-Energy Development (COED) System.......................... 11
      (2) Coalcon System................... 13
      (3) Clean Coke System................ 15
      (4) TOSCOAL System................... 16
      (5) ORC (Garrett) System............. 18
    d. Other Systems.......................... 20
      (1) Fischer - Tropsch System......... 20
      (2) Donor Solvent System............. 22
      (3) Methanol System.................. 24

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TABLE OF CONTENTS (cont'd)

Page

(4) Supercritical Gas Extraction System 26

2. Schedules 28

a. Catalytic Liquid Phase Hydrogenation ... 30

(1) Synthoil System 30

(2) H-Coal System 30

(3) Bergius System 30

b. Noncatalytic Liquid Phase Hydrogenation 31

(1) Solvent Refined Coal System 31

(2) COSTEAM System 31

c. Pyrolysis and Hydrocarbonization 31

(1) COED System 31

(2) Coalcon System 31

(3) Clean Coke System 31

(4) TOSCOAL System 32

(5) ORC (Garrett) System 32

d. Other Systems 32

(1) Fischer-Tropsch System 32

(2) Donor Solvent System 32

(3) Methanol System 32

(4) Supercritical Gas Extraction System 32

3. Status 33

a. Synthoil System 33

b. H-Coal System 34

c. Solvent Refined Coal System 34

TABLE OF CONTENTS (cont'd)

Page

d. Donor Solvent System.................. 36

e. Clean Coke System..................... 38

f. Bergius System........................ 39

g. Char-Oil-Energy Development (COED) System.................................. 39

h. COSTEAM System........................ 40

i. Coalcon System........................ 40

j. TOSCOAL System........................ 41

k. Occidental Research Corporation (Garrett) System...................... 41

l. Fischer-Tropsch System................ 43

m. Methanol System....................... 43

n. Supercritical Gas Extraction System.... 44

4. Priorities for Further Studies............. 44

a. Air Pollution Control................. 45

b. Water Pollution Control............... 45

c. Solid Waste Control................... 48

B. Current Environmental Background................ 50

a. Potential Pollutants and Impacts in All Media..................................... 51

2. Federal/State Standards, Criteria.......... 56

a. Federal Policy........................ 57

b. Selected State Policies............... 58

3. Other Regulatory Requirements (New or Pending)................................. 66

TABLE OF CONTENTS (cont'd)

Page

C. Environmental Objectives Development............ 68

  1. Criteria for Prioritizing.................. 68

  2. Methodologies Being Developed.............. 69

D. Environmental Data Acquisition.................. 71

  1. Existing Data for Each Process............. 71

  2. Identify Sampling and Analytical Techniques. 73

    a. The Phased Approach..................... 73

      (1) Level 1 Sampling and Analysis..... 74

      (2) Level 2 Sampling and Analysis..... 75

    b. Multimedia Sampling..................... 75

      (1) Classification of Streams for Sampling Process................. 75

      (2) Sampling Point Selection Criteria. 76

      (3) Stream Prioritization............. 79

    c. Data Requirements and Pre-Test Planning 79

      (1) Process Data Needs................ 79

      (2) Pre-Test Site Survey.............. 80

      (3) Pre-Test Site Preparation......... 81

    d. Sampling Equipment and Methodology..... 81

  3. Test Program Development................... 90

    a. Introduction............................ 90

    b. Test Plan for the SRC Pilot Plant...... 90

    c. SRC Combustion Test..................... 92

  4. Input-Output Materials Characterization..... 94

TABLE OF CONTENTS (cont'd)

Page

a. Reported Material Balances............ 95

b. Use of Reported Sample Analysis........ 95

c. Physical-Chemical Relationships........ 95

d. Analogies With Other Processes......... 96

e. Comparisons With Other Industries...... 96

f. Conceptualized Modeling of Missing Process Modules........................ 96

E. Technology Transfer (Input-Output).............. 102

1. Standards of Practice Manual................ 102

APPENDIX A - Process Flow Diagrams A-1

APPENDIX B - Federal and Selected State Regulations B-1

LIST OF TABLES

Table Page

1 Control Systems Assessment Requirements.......... 47

2 Input-Output Materials for 50,000 bbl/day Synthoil System.................................. 98

3 Input-Output Materials for 50,000 bbl/day H-Coal System.................................. 99

4 Input-Output Materials for 50,000 bbl/day Exxon Donor Solvent System...................... 100

5 Input-Output Materials for 50,000 bbl/day SRC System...................................... 101

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LIST OF FIGURES

Figure		Page
1	Process Development Operation Schedule	29
2	Basic Level 1 Sampling and Analytical Scheme for Particulates and Gases	77
3	Basic Level 1 Sampling and Analytical Scheme for Solids, Slurries and Liquids	78
4	High Pressure Line Grab Purge Sampling Apparatus	82
5	Low Pressure Grab Purge Sampling Apparatus (for Less than 2 Atmospheres Pressure)	83
6	Evacuated Grab Sampling Apparatus (for Subatmospheric Pressure)	84
7	Source Assessment Sampling Schematic	86
8	Expanded View of Connections of XAD-2 Cartridge to High Volume Sampler	87
9	Plug Collector for Fugitive Water Sample	88
10	Sampling Apparatus for HPHT (High Pressure High Temperature) Lines	89

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INTRODUCTION

Extensive research into the hydrogenation of coal was performed in the nineteen-twenties and thirties in Germany to utilize their large coal reserves for the production of liquid fuels. Interest in the United States was sporadic until the nineteen-sixties and seventies when it was realized that alternate sources of fuel were needed to augment the limited remaining reserves of petroleum.

Hittman Associates, Inc., is currently under contract to the Environmental Protection Agency to perform an environmental assessment of coal liquefaction technology. In order to accurately perform this assessment, individual studies have been initiated to further define the potential environmental effects of coal liquefaction. These individual studies have included; 1) an overview report of fourteen coal liquefaction systems which included process descriptions, major operations, input and output streams, process status, and process development schedules; 2) an indepth study of four processes (SRC, H-Coal, Synthoil, and Exxon Donor Solvent); 3) environmental field sampling of coal emissions from the burning of SRC fuel; 4) development of generalized process assessment criteria and techniques for prioritizing processes for generalized environmental assessments, and 5) acquisition of coal liquefaction product and waste stream data to estimate the environmental effects to be expected. These generalized study categories are the basis of this report and are explained in greater detail in the following sections.

Must of the information presented in this report represents work that is still in progress. As a result, the information is preliminary and should be used only as an indication of what is to come in future publications.

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MANAGEMENT SUMMARY

A. CURRENT TECHNOLOGY BACKGROUND

Estimates of current petroleum reserves indicate a limited remaining life for useful production of fuels. This has generated renewed interest in technology for producing liquid hydrocarbons from coal, with the primary objective of producing clean liquid fuels. Coal liquefaction is not a new technology, but dates back to the early part of the twentieth century and in principle even further than that.

With the entry into an era of declining petroleum reserves, reduced discoveries, escalation of prices, and real or induced shortages, coal liquefaction technology has once more assumed a major role as a potential solution to liquid fuel problems. Currently some twenty-odd systems are in various stages of development by industry and federal agencies. Four major generic processes of coal liquefaction technology can be identified. These are:

- Catalytic Liquid Phase Hydrogenation
- Noncatalytic Liquid Phase Hydrogenation
- Pyrolysis and Hydrocarbonization
- Other Systems

Each of the generic processes includes several specific processes.

1. CATALYTIC LIQUID PHASE HYDROGENATION

a. Synthoil System

The intent of the SYNTHOIL Process development was to show that, under the right conditions, reaction of coal with hydrogen will promote desulfurization and minimize additional hydrogenation of the products from the primary liquefaction. Work on such a process was initiated by the United States Bureau of Mines at the Pittsburgh Energy Research Center in 1969. It has led to a process in which coal is liquefied and desulfurized in a single step by catalytic hydrotreatment in a highly turbulent, co-current, up-flow, packed-bed reactor. Experimental work was carried

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out on various coals including Pittsburgh, Indiana No. 5, Middle Kittanning, Ohio No. 6, and Kentucky coal. All of these types of coal were satisfactorily converted to low-sulfur fuel oil with no appreciable attrition of catalyst or loss of catalyst desulfurization activity.

The Synthoil process is currently in the laboratory stage with construction of a process development unit underway. Operation of the process development unit is projected to begin in 1978 and continue into 1980. No firm plans for a pilot plant have been announced.

The Foster Wheeler Energy Corporation is responsible for the design and management of the construction of a 9.1 megagram (10-ton) per day process development unit to test the Synthoil process. However, recent communications from ERDA indicate that the process development unit may not be used for the Synthoil process. Pittsburgh Energy Research Center (PERC) is conducting support research for the design of the process development unit. PERC is also monitoring laboratory research on various aspects of the Synthoil process being conducted by ERDA's Sandia Laboratories and by the Argonne National Laboratory. Research on the Synthoil process is also being conducted by the Exxon Research and Engineering Laboratories and by the Battelle Memorial Institute Laboratories. These projects are being monitored by the Morgantown, Energy Research Center (MERC) in West Virginia.

The Hittman Associates, Inc. laboratories are running analyses of (1) the Synthoil product, (2) residue removed from the product by centrifugation, and (3) the stripping solution that had been used to remove hydrogen sulfide, ammonia and organic vapors from the off gas vented from the process. These materials were produced from a blend of four Kentucky bituminous coals.

b. H-Coal System

The direct hydrogenation process developed by Bergius in Germany for conversion of coal to liquid products led to later development in the U.S. of the H-Coal process. It was developed by Hydrocarbon Research, Incorporated (HRI) as a further application of the H-Oil process ebullating bed technology originally employed to convert heavy oil residues into lighter fractions. The ebullating bed catalytic reactor converts about 90 percent of the carbon contained in coal to a liquid. The feed to hydrogen manufacture is liquid rather than solid. The reactor configuration offers better temperature control, constant catalyst activity and a consistent quality of liquid product. An external hydrogen source is required. However, direct catalytic processes use less hydrogen in converting coal to liquids than do the noncatalytic or indirect catalytic hydrogenation processes.

The H-Coal process is being developed by Hydrocarbon Research, Inc. under the joint sponsorship of (1) ERDA, (2) a private industry consortium composed of Electric Power Research Institute, Ashland Oil, Inc., Conoco Coal Development Company, Mobil Oil Corporation and Standard Oil Company (Indiana), and (3) the Commonwealth of Kentucky. The overall objectives of the project are to further develop the H-Coal process and to demonstrate its technical and economic feasibility on a larger scale. Specific objectives are to, (1) conduct laboratory research on all phases of the H-Coal process using the existing bench-scale unit and process development to establish design criteria, (2) design a pilot plant capable of converting 545 megagrams (600 tons) of coal per day to 318 cubic metres (2,000 barrels) per day of low sulfur boiler fuel and (3) procure equipment and materials for the pilot plant. Objective (1) is continuing. Objective (2) has been realized as the ground was broken December 15, 1976 at Cattlettsburg, Kentucky. Determination of the feasibility of commercial production of liquid hydrocarbons from coal is the objective of this ninety-million dollar pilot plant.

c. Bergius System

Developed by Germany to produce aviation fuel and diesel oil during World War II, the Bergius process was one of the forerunners in coal liquefaction technology and has led to the recent development in the United States of the H-Coal and Synthoil processes.

The Bergius process is the ERDA "disposable catalyst" process. Construction of a process development unit is in progress and initial operation is planned for late 1977. No pilot plant plans currently exist.

2. NONCATALYTIC LIQUID PHASE HYDROGENATION

a. Solvent Refined Coal (SRC) System

The SRC process was originally developed by Spencer Chemical Company for the United States Department of the Interior, Office of Coal Research. Subsequently Gulf Oil acquired Spencer Chemical Company and development continues to the present under the Pittsburgh and Midway Coal Mining Company, part of Gulf Oil.

The SRC process requires no catalyst and low amounts of hydrogen relative to most alternative processes. The solid product is low in sulfur and ash, and has a high heating value. The major difficulties lie in operating costs for filtration and development of handling methods of the solid product.

Presently, there are two pilot plants operating, one in Wilsonville, Alabama and another in Fort Lewis near Tacoma, Washington. The plant at Wilsonville, Alabama will operate through 1977. A decision is to be made late in that year whether or not to continue operation.

Operational data from the Ft. Lewis plant will provide opportunities for (1) further study and development of the process, (2) accumulation of engineering and cost data for evaluation of commercial possibilities and design of demonstration or commercial plants, and (3) product evaluation and market development. Operation of the Fort Lewis, Washington facility is planned to extend into 1981.

In addition, a demonstration plant is being considered by the Kentucky Center for Energy Research but no schedule is available.

b. COSTEAM System

The Bureau of Mines has developed a new process, COSTEAM, that does not use hydrogen directly. In this process coal reacts with carbon monoxide and steam instead of hydrogen. It does not require a catalyst to convert low rank coals, such as lignite, into a low sulfur liquid fuel. There is usually enough water in lignite to supply the needs of the process. The water or steam supplies active hydrogen by reaction with the carbon monoxide. Alkaline carbonates are naturally occurring catalytic agents in lignite.

A process development unit was scheduled for completion in 1976. Operation beginning in 1977 and continuing into 1981 is planned.

3. PYROLYSIS AND HYDROCARBONIZATION

a. Char-Oil-Energy Development (COED) System

In the COED process, coal is heated in several types of fluidized bed at increasingly higher temperatures. This enables the process to handle caking coals without the preoxidation or recirculation of char usually necessary to prevent agglomeration in the system. This feature permits the achievement of high yields of oil with minimum sized equipment. An additional advantage is that the process operates at low pressure, less than 0.70 kg/cm^2 (0.68 Atm.) which permits the use of conventional oil processing equipment.

The COED project has been completed through the pilot plant stage. Dismantling of the pilot plant has been completed. No further work is projected for this process.

b. COALCON System

The Coalcon process is based on hydrocarbonization of coal. When heated in a hydrogen atmosphere, coal produces liquid, gaseous, and solid products. These materials are separated and treated to produce the final clean products. The solid material or char is then gasified with oxygen to produce a portion of the hydrogen rich gas required for hydrocarbonization.

Although originally planned for near term construction, ERDA is considering suspension of the project due to marginal economics and technical problems with fluid-bed carbonizers. Further work is proceeding to eliminate scale-up problems involved in fluidized bed and a decision will be made late in 1977 as to the fate of this project.

c. Clean Coke System

The Clean Coke process is being developed by USS Engineers and Consultants, Inc., a subsidiary of United States Steel Corporation, under the sponsorship of ERDA. The work was initiated in 1972 under the auspices of the Office of Coal Research (OCR, now a part of ERDA). The objective of the project is to design a pilot plant that is capable of converting low-grade, high-sulfur coal to low-sulfur, low-ash metallurgical coke, chemical feedstocks, and liquid and gaseous fuels.

The Clean Coke process combines coal carbonization and hydrogenation to produce solid, liquid, and gaseous fuel products. Char produced by carbonization is converted to coke which eliminates the problem of char use and disposal. No mechanical separation equipment is used to separate the solids from liquid product. Hydrogenation is noncatalytic and no external hydrogen is required. However, the hydrogenator operates at a very high pressure.

Laboratory and bench scale development studies on Illinois No. 6 Seam coal have been underway since 1969. Various aspects including coal preparation, carbonization/desulfurization of coal in fluidized beds, and high pressure hydrogenation reactions have been the subjects of these investigations. Process development units have been built and are now operating. Two additional types of coal are scheduled to be processed. Information obtained from the process development units will be used for the design of 218 megagrams (240 ton) per day pilot plant.

d. Occidental Research Corporation (Garrett) System

The Garrett Process is a solid phase hydrocarbonization process in which pulverized coal is almost completely converted to liquid and gaseous products in less than one minute. The process involves very rapid heating and devolatilization of pulverized coal in the absence of air, a short residence time in an entrained flow reactor, and a quick quench which prevents degradation of the liquid and gaseous products. Product distribution is strongly influenced by pryolysis temperature, with lower temperatures favoring liquid formation. The pyrolysis products can be further refined and purified to obtain synthetic crude oil, char which is suitable for combustion in an electric utility boiler, pipeline gas, and elemental sulfur.

Occidental Research Corporation (ORC) and the Commonwealth of Kentucky are in a joint venture for the purpose of preparing a detailed design for a 227-Mg (250-ton) per day pilot plant. A municipal waste processing plant of the same capacity is being constructed in San Diego County, California. ERDA's schedule calls for continued evaluation via process development unit operation into Fiscal Year 1978.

4. OTHER SYSTEMS

a. Fischer-Tropsch System

At this time, in the United States, studies based on the Fischer-Tropsch synthesis are of a fundamental research nature. No concrete plans have been made yet for process development or pilot studies in this country. A second large production plant is to be constructed in the coal fields of the Eastern Transvaal region in South Africa.

b. Donor Solvent System

Research was begun in 1966 to develop the basic Exxon Donor Solvent (EDS) process. It included studies on both hydrogenated and unhydrogenated recycle solvents. Equipment was tested in an integrated pilot plant system of 454 kilograms (one half ton) per day capacity. Techniques were developed for analyzing product and intermediate streams. Studies of process variables are continuing in a 907 kilogram (one ton) per day pilot plant.

The Energy Research and Development Administration and Exxon Research and Engineering Company of Florham Park, New Jersey have signed an agreement totaling $240 million to develop a process for producing liquids from coal. The project is based on Exxon's donor solvent coal liquefaction process. The program will involve both small-scale R&D work, and the design, construction and operation of a pilot plant with a capacity of 250 tons per day. The pilot plant will be built adjacent to an Exxon refinery at Baytown, Texas. The new agreement runs through December 31, 1982. The project is designed to bring donor solvent coal liquefaction technology to a stage where commercial plants could be designed and built by private industry.

c. Methanol System

Natural gas, reformed to synthesis gas, is currently preferred for methanol production in countries where it is available as a cheap feedstock. Prior to the advent of natural gas, solid fuels had been the major source for synthesis gas for methanol production. In the United States natural gas is no longer readily available and alternate sources for synthesis gas are being evaluated. Abundant coal reserves present in the United States may play an important role in synthesis gas production.

Some of the first generation systems that have been used to convert coal to synthesis gas are Koppers-Totzek, Lurgi and Winkler. The three systems employ different features and operating conditions, and each produces a gaseous product of different composition. A number of second generation processes are under development.

d. Supercritical Gas Extraction System

Two major problems facing advancement of coal liquefaction to commercialization are operability of solid-liquid separation equipment and high hydrogen consumption. The Supercritical Gas Extraction Process (SGE), now under development by National Coal Board in England seems to have solved these problems. Catalytic, Inc., a subsidiary of Air Products and Chemicals, Inc. is evaluating the technical feasibility of this process for United States coals. This process is at such an early stage of development that no plans beyond conception have been announced.

B. CURRENT ENVIRONMENTAL BACKGROUND

Based on the available literature with respect to potential pollutants resulting from coal liquefaction systems and conjunctive developments, Hittman Associates has attempted to identify the classes of major organic and inorganic substances (including organometallics) emanating from gaseous, aqueous, and solid waste emissions and effluents. Division of the pollutants into the organic and inorganic (or organometallic) groups is reasonable because these two groups differ in their chemical and physical properties; these properties in turn influence the environmental effects of the various pollutants. The physical and chemical properties of the organics have been discussed in terms of their classes. An effort was made to generalize on the known concentration of about seven inorganic, twenty-two trace and heavy metal elements, and nine major organic compounds, expected in nine major environmental compartments, (soil, rock, freshwater, seawater, air, plants, marine, terrestrial, and animals) as an aid in estimating whether the increased inputs of these elements when released in the ash, etc. from coal liquefaction, would significantly increase the level in the environment.

One of the more significant aspects of the ongoing environmental assessment effort by Hittman Associates has involved the critical analysis of natural physical-chemical processes that effectively dissipate or enhance the toxic effects of known biological stressors in aqueous and solid waste effluents. Another important effort refers to the attempt made by Hittman Associates to identify those living organisms judged by the 96-hour LD_{50}, to be the most sensitive vis-a-vis such organic pollutants as benzene, acenapthene, anthracene, chrysene, toluene, 3,4-benzopyrene-isophorone, and benzidine, among others. Organisms were identified among the marine microorganisms (algae, bacteria, etc.) fresh-water algal, terrestrial microorganisms, selected higher plants, marine invertebrates, freshwater invertebrates, marine and freshwater fishes, amphibians, and non-human mammals. One of the least studied areas relates to the additive interactions between mixtures of such aqueous pollutants as phenols, metals, ammonia, and mixtures of ammonia, phenol, zinc, copper and cyanide. An effort was made to demonstrate more clearly the synergistic and antagonistic interactions of a number of compounds.

Present indications as to chronic effects of major pollutants, based on the study of coal-derived products, are as follows:

- Sulfur-containing constitutents (in the reduced state) are present in a much greater variety and, in some cases, larger quantities than was anticipated. The ecological and health effects of reduced sulfur compounds has not been studied intensively.
- Concentrations of polynuclear aromatic hydrocarbons are very high. A detailed study of this fraction is called for to properly estimate the general threat of industrial carcinogensis. BaP concentrations in aqueous liquors suggest an environmental hazard.
- Concentrations of weakly acidic components, suspected tumor promotors or co-carcinogens, are substantial and a wide variety occur.
- Nitrogen heterocyclics are present at substantial levels suggesting the need for additional studies. High indole/skatole concentrations suggest the possible presence of carcinogenic dibenzacridine.

Consistent with the objective of evaluating coal liquefaction systems, a review of existing environemtal requirements was made at the Federal and State government levels. The study of state laws was restricted to those states which have the demonstrated coal reserves necessary to provide sites for commerical coal liquefaction facilities in the near and far term. The states which have been addressed are Alaska, Arizona, Colorado, Illinois, Indiana, Kentucky, Montana, New Mexico, North Dakota, Ohio, Pennsylvania, South Dakota, Texas, Utah, West Virginia and Wyoming.

The major conclusion of the review is that no legislation currently exists directly pertinent to coal liquefaction processes. Prior to commercialization such legislation will be needed at the federal, state and local levels. Additionally, existing standards governing related fossil fuel technologies could serve as the foundation on which standards for liquefaction facilities will be based. However, at this time it is impossible to project how stringent and how comprehensive environmental regulations will be specific to commercialized coal liquefaction systems.

C. ENVIRONMENTAL OBJECTIVES DEVELOPMENT

In conjunction with the development of Environmental Characterizations, a preliminary effort was completed to establish study priorities for the development of coal liquefaction technologies and control needs. The candidate systems were those most advanced from a development standpoint and those considered to be of possible interest to commercial developers and industrial users. The result of this prioritization is a comparative rating and evaluation of the systems established on the basis of projected needs for detailed study and environmental characterization. The order of ranking for the candidate systems in coal liquefaction technology is as follows:

- Solvent Refined Coal
- H-Coal
- Exxon Donor Solvent
- Synthoil
- COED
- COSTEAM
- Clean Coke
- Fischer-Tropsch
- ORC (Garrett)
- Coalcon
- Methanol Synthesis
- TOSCOAL
- Bergius

IERL-RTP is currently developing an environmental assessment methodology especially related to the Federal Interagency Energy/Environment R&D Program in support of standards develoment. The environmental assessment methodology will consist of various methodology components being developed with the assistance of participating contractors. One such specialized component is the development of process assessment criteria which will be used to set priorities with regard to the selection of processes for further study in environmental assessment. Hittman Associates' task, called Process Assessment Critiera, consists broadly of:

- delineating criteria to be considered in evaluating processes (to set priorities for further study),

- assigning these criteria a normalized set of relevance weights, based on a rational decision analysis method, and

- preparing step-wise instructions which will permit application of this methodology component for a generalized environmental assessment.

D. ENVIRONMENTAL DATA ACQUISITION

Existing data for the environmental discharges on the different systems are fragmentary and usually may be characterized as (1) product and waste descriptions based on hydrocarbon chain length, boiling point ranges, viscosities, and element contents (sulfur, nitrogen, carbon-hydrogen ratios, metals, etc.), (2) qualitative analysis for specific organic compounds, often for known carcinogenic effects, and (3) out-of-date and/or partial quantitative analysis of products. Since there is no available overall quantitative analysis of product and waste discharges from an existing coal liquefaction systems, Hittman Associates is currently preparing reports which will provide a preliminary estimate of such discharges for four systems - Solvent Refined Coal, Synthoil, H-Coal and Exxon Donor Solvent.

At this point in the input characterization development, the similarities should be stressed rather than differences. For example, the bottoms fraction from the EDS process consist of 4,866 tons per day, while the Synthoil process has only 3,536 tons per day of char after pyrolysis through a multiple hearth furnace (conceptualized by Synthoil developers). Pyrolysis or other treatment of EDS bottoms could reduce the amount of bottoms to a lower figure comparable to the Synthoil char. Similar treatment could reduce the 5482 tons per day of solid wastes from the H-Coal process. The similarity is that all four processes have 3500 to 5500 tons per day of solid and residue waste for use/treatment/disposal. This quanity of solid and residue waste represents a significant area of environmental discharge which needs to be given priority attention. Similar attention needs to be given to treatment/control equipment for process wastewater and air emissions.

Hittman Associates is currently preparing an environmental characterization report which will discuss the literature and other available data on the environmental effect of the products from coal liquefaction systems. Environmental effects for coal liquefaction facilities may be expected from (1) atmospheric emissions of particulates, sulfur and nitrogen compounds, and other volatiles, (2) wastewater contaminants such as acids, phenols, organics, cooling tower chemicals and inorganic compounds, (3) solid and residue wastes such as ash, still bottoms, char, spent catalyst, and filtered solids, and (4) the products. Most of the existing data for environmental effects are for the product, or the solid and residue wastes. As laboratory analysis of product and waste streams for quantitative measurement of toxic and hazardous chemicals becomes available, Hittman Associates will attempt to estimate the environment effects to be expected from quantified discharges.

During the past year work was performed on two major test programs. A suggested sampling plan for the Ft. Lewis, Washington Solvent Refined Coal Pilot Plant, operated by Pittsburgh and Midway Coal Mining Company, is nearing completion. The purpose of this plan is to provide guidance in a multimedia sampling program. Much of the information was exerpted from the IERL-RTP Procedure Manual: Level 1 Environmental Assessment (EPA-600/2-76-160a). The phased approach and sampling methodologies were the basis for the document.

A test plan was also developed for a combustion test at Georgia Power Company's Plant Mitchell where Solvent Refined Coal was burned for the first time in a commercial utility boiler. The test occurred, and samples were collected. A paper on the subject was delivered at the EPA Symposium on Environmental Aspects of Fuel Conversion Technology, III in Hollywood, Florida. The major portion of the analysis is currently being performed and a final report of the test will be prepared when these results are available.

E. TECHNOLOGY TRANSFER

The first Standards of Practice Manual for a coal liquefaction systems is under preparation by Hittman Associates, Inc., Columbia, Maryland. The Standards of Practice Manual is designed to furnish environmental guidelines and best control/disposal options for liquefaction processes currently under development.

The SRC-1 system was chosen for the study. A pilot plant for the system has been operated by ERDA at Fort Lewis, Washington since September 1974. It was felt that a definitive study of the process and its waste streams, and their optimum treatment methodologies would provide a service to the future commercialization of this process.

Progress includes completion of material balances for the process and waste streams. From this basis, written and schematic descriptions of process modules and control/disposal modules were added. Best control/disposal practices have been selected for all wastestreams. Partially complete are descriptions of environmental emissions and factors achievable and control/ disposal costs.

Remaining work includes a detailed description of the basic process, which will outline control options for specific emissions and their respective costs for each process module. A large portion of this effort will consist of assembling information from previous sections of the manual and summarizing them into clear, succinct unit operations for each process module.

A. CURRENT TECHNOLOGY BACKGROUND

With the entry into an era of declining petroleum reserves, reduced discoveries, escalation of prices, and real or induced shortages, coal liquefaction technology has once more assumed a major role as a potential solution to liquid fuel problems. Currently some twenty-odd processes are in various stages of development by industry and federal agencies. Four major generic processes of coal liquefaction technology can be identified. These are:

- Catalytic Liquid Phase Hydrogenation
- Noncatalytic Liquid Phase Hydrogenation
- Pyrolysis and Hydrocarbonization
- Other Systems

Each of the generic processes includes several specific processes.

A wide range of process conditions and configurations exist within the liquefaction technology. Characterization of the more important processes is presented in the remainder of this section. Flow diagrams for each system discussed can be found in Appendix A.

1. SYSTEM INFORMATION

a. Catalytic Liquid Phase Hydrogenation

(1) Synthoil System*

The intent of the SYNTHOIL Process development was to show that, under the right conditions, reaction of coal with hydrogen will promote desulfurization and minimize additional hydrogenation of the products from the primary liquefaction. Work on such a process was initiated by the United States Bureau of Mines at the Pittsburgh Energy Research Center in 1969. It has led to a process in which coal is liquefied and desulfurized in a single step by catalytic hydrotreatment in a highly turbulent, co-current, up-flow, packed-bed reactor. The initial work used a reactor with an internal diameter of 0.79 cm. (0.3125 in) with daily feed rates of 22 kg (48 lb.) of coal or 54 kg (120 lb.) of slurry. Experimental work was carried out on various coals including Pittsburgh, Indiana No. 5, Middle Kittanning, Ohio No. 6, and Kentucky coal. All of these types of coal were satisfactorily converted to low-sulfur fuel oil with no appreciable attrition of catalyst or loss of catalyst desulfurization activity. Other parameters investigated were hydrogen flow rate, coal content of feed slurry, recycle of product oil, and the effects of hydrogen sulfide on recycle gas. A larger bench-scale unit, 2.8 cm (1.1 in.) internal diameter and 4.42 m (14.5 ft) long, was operated at daily feed rates up to 181 kg (400 lb.) of coal and 454 kg (1/2 ton) of slurry. Reactor pressure was varied from 145 to 290 kg/cm^2 (140 to 280 atms.) at temperatures up to 450°C (840°F). High yields of low sulfur (0.19 to 0.3 percent) and low-ash (one percent) fuel oil ranged from 525 to 700 liters per metric ton of coal (3 to 4 barrels per ton). The lower reactor pressure corresponded to lower values of yield, heating value and hydrogen consumption. Sulfur and ash content of the low pressure oil were higher than those of the oil made at 290 kg/cm^2 (280 atm.). Operation at the lower pressure is desirable provided an environmentally acceptable product can be made. An 11 metric-ton per day process development unit is under construction.

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* (Ref. Fig.1, App. A.)

Coal feed for the SYNTHOIL Process is prepared by drying and then grinding to 90 percent through 60 mesh or 65 percent through 200 mesh. The ground coal is thoroughly mixed with recycled product oil to form a paste or slurry containing about 40 percent coal and 60 percent oil. The slurry, together with recycled and makeup hydrogen, is preheated and then passed to the reaction zone. The reactor is packed with eighth-inch pellets of a commercial catalyst of the type used in desulfurizing petroleum derivatives. Under operating conditions of 140 to 280 kg/cm^2 (136 to 271 atm.), 450°C (840°F) and a superficial gas velocity of 1.83 m (6 ft) per sec., hydrogen liquefies the coal and removes sulfur, oxygen, and nitrogen from it.

The major portion of the coal is hydrogenated to gas and oil which are separated by a pressure reduction. The oil stream containing SYNTHOIL, residue, and mineral matter is treated to separate the oil and solids. The oil is divided into two streams, one of which is returned to feed preparation and the other withdrawn as product. Residue and oil are separated; the oil is sent to product storage and the residue goes to the hydrogen production area. The gaseous mixture from the reaction contains unused hydrogen which can be recycled through the reactor. However, it also contains hydrogen sulfide and ammonia. These two contaminants are removed by absorption in the gas purification system. The hydrogen sulfide is sent to a sulfur recovery unit and the ammonia is used to produce ammonium sulfate. Sulfuric acid also may be produced.

Coal and residue from the reactor are used to produce a rich hydrogen (97.5 percent) mixture to use in the liquefaction reaction.

Major Operations and/or Modules

- Sizing, drying and slurrying
- Hydrogenation
- Separation
- Hydrogen production

Input and Output Streams

- Input Streams

  Coal
  Catalyst - Co-Mo/SiO_2-Al_2O_3
  Hydrogen
  Monoethanolamine (MEA)
  Water

- Output Streams

  SYNTHOIL
  Sulfur
  Ammonium Sulfate
  Sulfuric Acid
  Ash
  Carbonaceous residue
  Water from coal drying
  Dust from crushing
  Fuel gas
  Tar
  Spent catalyst
  Spent MEA
  Waste liquids, oil, and water
  Blowdown and sludge from:

  - Power plant
  - Water treatment
  - Cooling tower

(2) H-Coal System*

The direct hydrogenation process developed by Bergius, in Germany, for conversion of coal to liquid products led to later development in the U.S. of the H-Coal process. It was developed by Hydrocarbon Research, Incorporated (HRI) as a further application of the H-Oil process ebullating bed technology originally employed to convert heavy oil residues into lighter fractions. The ebullating bed catalytic reactor converts about 90 percent of carbon contained in coal to a liquid. The feed-to-hydrogen manufactured is liquid rather than solid. The reactor configuration offers better temperature control, constant catalyst activity, and a consistent quality of liquid product. An external hydrogen source is required. However, direct catalytic processes use less hydrogen in converting coal to liquids than do the noncatalytic or indirect catalytic hydrogenation processes.

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* (Ref. Fig.2, App.A.)

Major Operations and/or Modules

- Sizing, Drying, and Slurrying. The coal is crushed to about 18 mm (3/4 in) and stockpiled. For feed preparation, it is dried to 4 percent moisture, and then ground to minus 60 mesh. Crushed coal is mixed with recycled oil to form a slurry feed for the high pressure hydrogenation module.

- Hydrogenation. Coal slurry and hydrogen are passed through a preheated furnace and then fed to the bottom of the reactor. The liquid slurry is hydrogenated as it comes in contact with the ebullating bed of catalyst. The reaction takes place at a temperature of about 455°C (850°F) and pressure of about 206 kg/cm^2 (200 atm). Fresh catalyst is added to replace the used catalyst on a semi-continuous basis which permits reactor operation at a constant equilibrium activity level.

- Product Separation. Gases and vapors are withdrawn from the top of the reactor and passed through condensers. Condensed oil vapors are sent to an atmospheric distillation unit. Further cooling of gases condenses a large amount of sour water containing ammonia, hydrogen sulfide, phenols, light oil, and suspended solids. Uncondensed gases are passed through an acid gas removal unit where hydrogen sulfide is removed and further processed to elemental sulfur. Part of the clean gas is used as plant fuel and part is recycled to the main reactor system. Fresh hydrogen is added to achieve the required concentration for use in the main reactor.

- Solids Separation. The heavier portion of the product oil leaves as a sidestream from the liquefaction reactor. It contains particulates such as mineral matter and unreacted coal which must be removed. The hot oil is flashed in a separator and the vapors are condensed and pumped to an atmospheric distillation unit.

- Distillation. The bottoms product from the flash separator is further separated with a hydrocyclone, a liquid-solid separator, and a vacuum still. The overhead is a heavy oil refinery feedstock. The stream removed from the bottom of the vacuum tower contains heavy liquid residue together with some particulates. The bottoms product from the distillation unit is recycled for slurry preparation and the overhead stream of light liquid hydrocarbons is further refined as necessary. Synthesis gas for use in making hydrogen can be generated by using the slurry bottoms from the vacuum tower as feed to a slagging type gasifier. Supplemental coal feed may be needed.

Input and Output Streams

- Input Streams

  Coal
  Stream
  Air
  Catalyst
  Absorption solvent

- Output Streams

  Synthetic oil
  Sulfur
  Ammonia
  Ash
  Residue
  Spent catalyst
  Spent solvent
  Water from coal drying
  Dust from coal crushing
  Fuel gas
  Tar
  Waste liquids, oil, and water
  Blowdown and sludges from:

    - Power plant
    - Water treatment
    - Cooling tower

(3) Bergius System*

Developed by Germany to produce aviation fuel and diesel oil during World War II, the Bergius process was one of the forerunners in coal liquefaction technology and has led to the recent development in the United States of the H-Coal and Synthoil processes. Coal from the stockpiles is dried and finely ground. It is then mixed with process derived hydrocarbon liquid to form a paste containing approximately 40 percent coal. The paste is pressurized to about 700 kg/cm^2 (677 atm.) and heated to a temperature of 430°C (810°F). The heated paste and the recycled hydrogen-rich gas are then fed to a catalytic reaction zone.

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* (Ref. Fig.3, App.A.)

The products from the first reaction are separated into an overhead gaseous stream, a light oil stream, and a heavy oil stream which contains unreacted coal and mineral matter. The overhead hydrogen rich gas is scrubbed to remove any particulate matter and recycled to the reactor. The light oil stream is further treated over a catalyst to produce materials similar to petroleum. The heavy oil stream is treated to separate untreated coal, catalyst, and mineral matter from the oil. Recovered oil is recycled to the paste preparation area.

Major Operations and/or Modules

- Drying, Sizing, and Pasting
- Hydrogenation
- Separation

Input and Output Streams

- Input Streams

  Coal
  Hydrogen
  Water
  Catalyst

- Output Streams

  Carbonaceous residue
  Light oil
  Middle oil
  Wastewater
  Spent catalyst
  Sulfur
  Ammonia
  Dust
  Fuel gas
  Tar
  Waste oil
  Blowdown and sludges from:

    - Power generation
    - Water treatment
    - Cooling towers

b. Noncatalytic Liquid Phase Hydrogenation

(1) Solvent Refined Coal System*

Two alternatives are being pursued for electric power generation. One is to burn coal directly and remove particulates and SO_2 by scrubbing the stack gases; the other is to refine or clean the coal by removal of sulfur and ash or mineral matter before it is fired in the utility steam generator and, thus, obviate the need for stack gas cleaning. Solvent Refined Coal (SRC) represents the second alternative and is receiving prominent consideration. The process requires no catalyst and low amounts of hydrogen relative to most alternative processes. The solid product is low in sulfur and ash and has a high heating value. The major difficulties lie in operating costs for filtration and development of handling methods of the solid product.

Major Operations and/or Modules

- Sizing, Drying, and Slurrying. As the coal is received, it is separated according to lump size. Lumps smaller than three- by six-inches are sent to a primary crushing step which reduces the size to three-quarters of an inch. Large lumps are crushed to three- by six-inches and returned to the primary crushing step. Sized coal, three-quarters of an inch, from the primary crushing step is stored. The stored coal is transferred to the pulverizer system. This system simultaneously grinds the coal to about 200 mesh size and dries it to one- to three-percent moisture. Fines less than 200 mesh size from both primary and pulverizing, can be used to produce hydrogen for the hydrogenation step. The pulverized dry coal is slurried with solvent.

- Hydrogenation. A 70 to 85 percent hydrogen gas mixture is added to the coal/solvent slurry. These materials are first preheated and subjected to the conditions of the hydrogenation operation. Depending on the nature of the coal and its sulfur content, the temperature range is 425° to 495°C (800° to 925°F) and the pressure range is 70 to 140 kg/sq. cm. (68 to 136 atm.). Other variables which affect this operation are the partial pressure of hydrogen, the residence time, and the solvent-to-coal ratio. These variables are not independent, i.e, a change in one may cause changes in the others. This helps to provide flexibility to the process, permitting the output of a heavier or lighter product; the lighter product having the higher hydrogen content.

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* (Ref. Fig.4, App.A.)

The hydrogenation or liquefaction operation produces a mixture of gases, vapors, liquids, and solids. This mixture is cooled to 290°C (550°F) and the vapor and gases are separated from the liquids and solids by a series of pressure reductions. The vapors, consisting of light hydrocarbons, heavy hydrocarbons and water, are condensed and collected.

- Solids Separation. The mixture of coal solution and solids is separated by filtration or centrifugation. The solids contain mineral matter and undissolved coal. This residue is cooled to 38°C (100°F) and stored. It can be gasified to produce the hydrogen required in the process.

- Solvent Recovery. Liquid material from the solids-liquids system separation is heated to 425° to 470°C (800° to 875°F) at about 7 kg/cm^2 (6.8 atm.). All the unused process solvent and lighter liquids are vaporized. The remaining material is the molten solvent refined coal. The molten product is cooled from 316°C (600°F) to about 66°C (150°F) at which temperature it is solid.

- Gas Cleaning. In the hydrogenation operation, most of the sulfur in the coal is converted to hydrogen sulfide and other gaseous compounds. Excess hydrogen is used in the operation and unused hydrogen can be recycled. However, it must first be "cleaned" to remove gaseous sulfur compounds. A number of patented processes are available for this purpose, some remove carbon dioxide as well as hydrogen sulfide. After the hydrogen sulfide is removed from the gas stream, the solution used to absorb it is stripped to yield a concentrated hydrogen sulfide gas from which elemental sulfur is produced.

Input and Output Streams

- Input Streams

  Coal
  Steam, water
  Air
  Start-up solvent
  Absorption solvent

- Output Streams

  Solvent refined coal
  Ash slag or ash

Hydrocarbon gases
Water (process, storm drainage from coal storage, and preparation)
Spent catalyst
Sulfur
Ammonia
Coal dust
Tar
Waste liquids, oil, and water
Blowdown and sludges from:

- Power plant
- Water treatment
- Cooling towers

(2) COSTEAM System*

The Bureau of Mines has developed a new process, COSTEAM, that does not use hydrogen directly. In this process coal reacts with carbon monoxide and steam instead of hydrogen. It does not require a catalyst to convert low rank coals, such as lignite, into a low sulfur liquid fuel. There is usually enough water in lignite to supply the needs of the process. The water or steam supplies active hydrogen by reaction with the carbon monoxide. Alkaline carbonates are naturally occurring catalytic agents in lignite.

Lignite is pulverized and mixed with some of the product oil. This slurry is fed to the reactor which operates at a temperature of 380° to 400°C (720° to 790°F) and a pressure of 210 to 280 kg/cm^2 (203 to 271 atm.). Synthesis gas or carbon monoxide is fed to the reactor at high pressure. Synthesis gas or carbon monoxide reacts with water contained in the lignite to produce hydrogen which then reacts with lignite to form a liquefied coal product.

Product gas is separated from the product liquid stream in a pressure reduction step. The liquid fuel product stream contains unreacted solids and ash which are removed by centrifugation. The unreacted solids residue can be utilized to produce the synthesis gas required by the process. The product fuel oil can also be further hydrogenated to obtain gasoline.

Major Operations and/or Modules

- Sizing and Slurrying
- Hydrogenation
- Solids separation
- Synthesis gas manufacture

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* (Ref. Fig.5, App.A.)

Input and Output Streams

- **Input Streams**

  Coal
  Water
  Synthesis gas

- **Output Streams**

  Fuel oil
  Unreacted solids
  Product gas
  Residue
  Coal dust
  Tar
  Waste liquids, oil, and water
  Blowdown and sludges from:

  - Power plants
  - Water treatment
  - Cooling tower

c. Pyrolysis and Hydrocarbonization

(1) Char-Oil-Energy Development (COED) System*

In the COED system, coal is heated in several stages of fluidized beds at increasingly higher temperatures. This enables the process to handle caking coals without the preoxidation or recirculation of char usually necessary to prevent agglomeration in the system. This feature permits the achievement of high yields of oil with minimum sized equipment. The foregoing are the major advantages of the COED process. An additional advantage is that the process operates at low pressure, less than 0.70 kg/cm^2 (0.68 atm.) which permits the use of conventional oil processing equipment.

Major Operations and/or Modules

- Sizing and Drying. Coal is crushed and dried simultaneously. This operation reduces the particle size to about 1.6 mm (1/16 in.) and removes from 60 to 70 percent of the moisture in the coal. The remaining moisture is evolved in the first stage of pyrolysis. The milling operation takes place in a gas swept atmosphere under a slight vacuum, at 70°C (160°F).

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*(Ref. Fig.6, App.A.)

- Pyrolysis. A mixture of combustion and recycled gases fluidizes and heats the coal to about 175°C (350°F) in the first pyrolysis stage. The coal is partially devolatilized and the gases evolved are scrubbed with recycled liquor and cooled.

The partially devolatilized coal from Stage I (Fig.7, App.A.) is passed to Stage II. Stages II, III, and IV (Fig.8, App.A.) are located on successively descending levels and are coupled closely to minimize heat losses and pressure drops. The cascaded arrangement permits gravity flow of the char between the stages. Superheated steam and oxygen are injected at the bottom of Stage IV. Stage IV operates at 815°C (1500°F) and the hot gases pass countercurrently through Stages III and II, providing the fluidizing medium. Stages II and III operate at about 430°C (810°F) and 540°C (1000°F) respectively.

All stages are equipped with internal particulate separation systems to remove entrained solids from the exit gases. Most of the volatile matter contained in the coal is evolved in the second stage. The rest of the volatile matter evolves in the third and fourth stages. The pyrolysis gases and oil vapors from the second stage pass through an external particulate separation system to remove solids which would otherwise collect in and plug subsequent processing steps. They are treated next in an absorption system which removes the oil vapors, treated for removal of hydrogen sulfide and carbon dioxide, and then used as product gas.

Oil and water condensed from the pyrolysis gas/vapor stream are separated into two oil fractions, one heavier and one lighter than water, and an aqueous fraction. The two oil fractions are dehydrated and sent to filtration. The aqueous phase is cooled and recycled to the scrubbers. Hot char is discharged from Stage IV to a fluidized bed cooling step which generates high pressure steam. Recycled gas from Stage 1 is used to fluidize the cooling char.

- Filtration. Oil from the product recovery system may contain some char particles which would plug the catalyst bed in the hydrotreating operation. These particles are removed by filtration. Hot filter cake consisting of char, oil, and filter aid is discharged to char storage. Filtered oil goes to the hydrotreating area.

- Hydrotreating. The filtered oil contains small amounts of sulfur, nitrogen, and oxygen as impurities. To improve its properties the oil is treated with hydrogen. This treatment also converts the impurities into hydrogen sulfide, ammonia, and water which are then separated from the product oil.

Input and Output Streams

- **Input Streams**

  Coal
  Steam
  Air
  Oxygen
  Catalyst
  Absorption solvent

- **Output Streams**

  Synthetic oil
  Sulfur
  Ammonia
  Ash
  Spent catalyst
  Spent solvent
  Low-Btu gas
  Char
  Filter cake
  Pyrolysis gas
  Wastewater
  Tar
  Waste oil

(2) Coalcon System*

The Coalcon system is based on hydrocarbonization of coal. When heated in a hydrogen atmosphere, coal produces liquid, gaseous, and solid products. These materials are separated and treated to produce the final clean products. The solid material or char is then gasified with oxygen to produce a portion of the hydrogen-rich gas required for hydrocarbonization.

Major Operations and/or Modules

- Sizing and Drying. Coal is received, unloaded, and stockpiled. It is then crushed and ground to 60 to 325 mesh. The coal is dried to about 1 percent moisture.

- Hydrocarbonization. The prepared coal is preheated and is injected into the reaction zone with pressurized hydrogen. In the reaction zone the temperature is 560°C (1040°F) and the pressure is 39 kg/cm^2 (37.8 atm.). Other variables that affect the yield of products are residence time, partial pressure of hydrogen, and superficial gas velocity. Solid particles carried out by the gas stream are recovered and combined with the char.

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* (Ref. Fig.9, App.A)

- Product Recovery. The gas and vapors are separated into gas, light oil, heavy oil, and wastewater streams. A portion of the heavy oil is recycled to the scrubbing step which removes any solids which may have escaped with the gas. The recycled mixture is then fractioned into a heavy fuel stream and overhead stream. The heavy oil product is cooled and pumped to storage. Ammonia generated in the process is recovered as a by-product. The acid gas removal step absorbs CO_2, H_2S, and aromatics from the gas. The H_2S is recovered as elemental sulfur.

- Hydrogen Generation. Gas from the acid-gas removal step is processed by cryogenic separation into a purified hydrogen stream, which will be recycled to the hydrocarbonization reactor; a synthesis gas stream, which is further processed to make substitute natural gas; and a liquefied hydrocarbon stream.

Char from the hydrocarbonization step is gasified with steam and oxygen to generate hydrogen.

Input and Output Streams

- Input Streams

  Coal
  Steam
  Oxygen
  Absorption solvent
  Ammonia recovery solvent
  Hydrogen

- Output Streams

  Heavy fuel oil
  Light fuel oil
  Ammonia
  Sulfur
  Substitute natural gas
  Liquefied hydrocarbon gas
  Ash
  Spent catalyst
  Waste liquids, oil, and water
  Aromatic chemicals
  Blowdown and sludges from:

    - Power plant
    - Water treatment
    - Cooling tower

(3) Clean Coke System*

The United States Steel Engineers and Consultants, Inc., a subsidiary of United States Steel Corporation, is developing a system to convert low grade, high sulfur coal to clean metallurgical coke, chemical feedstocks, and liquid and gaseous fuels. The system is known as the Clean Coke Process and is sponsored by ERDA.

The process can be divided into carbonization and hydrogenation sections. Required hydrogen is produced within the process itself. The process design provides for operating the plant as a closed system thus eliminating some of the environmental problems.

Run of mine coal is dried, crushed, and ground. Approximately half of the prepared coal is conveyed to the carbonization section and the rest to the hydrogenation section.

In the carbonization section, coal is pyrolyzed in a fluidized bed zone operating at temperatures of 705° to 760°C (1300° to 1400°F) and pressures of 7 to 10 kg/cm^2 (6.8 to 9.7 atm.). The fluidizing medium is hydrogen-rich recycled gas. The products from the carbonization section are char, a liquid stream which is directed to the liquid processing section; and a hydrogen-rich gas which is recycled to the reactor. The char is pelletized with process derived heavy oil, and the pellets are heated in the absence of oxygen to produce low sulfur metallurgical coke and a hydrogen-rich gas. Part of the gas is recycled to the carbonization step and the rest is sent to gas clean up.

In the hydrogenation section, prepared coal is mixed with a process derived oil to form a coal/oil slurry. The slurry is fed to a high pressure, noncatalytic hydrogenation zone along with hydrogen from the gas cleanup section. The hydrogenation section operates at pressures of 207 to 310 kg/cm^2 (200 to 300 atm.). The slurry feed is converted to a chemical rich liquid and a gas rich in light paraffins. These products are separated from the unconverted coal and mineral matter. Condensate from the vapor goes to a processing section where light, medium, and heavy oil are separated. Light oil is further processed to obtain chemical feedstocks, which include gasoline, benzene, napthalene, and residual tars. Medium oil is used for slurry preparation. Part of the heavy oil is used in the pelletizing step, with the rest being fed to the carbonization section. Uncondensed gases are sent to the gas treatment section for separation into chemical feedstocks, which include ethylene and propylene, ammonia, sulfur, and fuel gas. Recovered hydrogen is recycled to the hydrogenation section.

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*(Ref. Fig.10, App.A.)

Major Operations and/or Modules

- Sizing and Drying
- Carbonization
- Hydrogenation
- Product separation

Input and Output Streams

- Input Streams

  Coal
  Water
  Hydrogen

- Output Streams

  Metallurgical coke
  Chemical feedstocks
  Ash and unreacted coal
  Waste liquids, oil, and water
  Tar acids
  Tar bases
  Oil
  Organic chemicals
  Gasoline
  Sulfur
  Fuel gas
  Ammonia
  Hydrogen
  Blowdown and sludges from:

    - Power plants
    - Water treatment
    - Cooling tower

(4) TOSCOAL System*

The Oil Shale Corporation (TOSCO), in cooperation with other private industries, has developed a process for retorting oil shale, known as the TOSCO II process. This process has been adapted to use coal. Run of mine coal received in the coal preparation and handling is unloaded, crushed, and stored in piles. The coal is then ground, dried, and preheated. The coal is partially devolatilized and fines carried over are removed from the vapors in a gas solid separation system. The vapor is passed to a scrubbing system and the preheated coal is sent to a pyrolysis reactor. Here the coal is heated to carbonization temperatures of 427° to 537°C (800° to 1000°F) by contact with hot ceramic balls.

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*(Ref. Fig.11, App.A.)

The char product leaves the pyrolysis zone and is subsequently cooled and sent to storage. Cool, ceramic balls are returned to a ball heating system. Pyrolysis vapor is cooled to condense oil and water and to separate gaseous products. Oil and water are separated. The oil is distilled to yield gas oil, naphtha, and residuum. Uncondensed gas is used as fuel for heating the balls.

Major Operations and/or Modules

- Sizing and Drying
- Pyrolysis
- Product separation
- Gas purification

Input and Output Streams

- Input Streams

  Coal
  Air
  Water

- Output Streams

  Char
  Fuel oil
  Fuel gas
  Wastewater
  Flue gas
  Naphtha
  Gas oil
  Coal dust
  Ash
  H_2S
  CO_2
  Blowdown and sludges from:

  - Power plant
  - Water treatment
  - Cooling tower

(5) ORC (Garrett) System*

The ORC Process is a solid phase hydrocarbonization process in which pulverized coal is almost completely converted to liquid and gaseous products in less than one minute. At 141 kg/cm^2 (136 atm.) and 500°C (930°F), the yield is up to 30 percent distillable liquid, 40 percent tar, and the balance gas. The reaction is faster if a solution of ammonium molybdate is spread on the coal. Tests using a 15 percent stannous chloride catalyst indicate conversion in a few seconds to 55 percent liquid, 40 percent gas, and 5 percent tar. Coal feed size is about 200 mesh. The fast reaction time should permit savings in capital costs for reactors.

ORC's coal pyrolysis system is being developed with the aim of maximum liquid yield. The process involves very rapid heating and devolatilization of pulverized coal in the absence of air, a short residence time in an entrained flow reactor, and a quick quench which prevents degradation of the liquid and gaseous products. Product distribution is strongly influenced by pyrolysis temperature, with lower temperatures favoring liquid formation. The pyrolysis products can be further refined and purified to obtain synthetic crude oil; char, which is suitable for combustion in an electric utility boiler; pipeline gas; and elemental sulfur.

Coal is first dried and pulverized as it would be for a utility boiler. The coal is then conveyed pneumatically with recycled product gas to the pyrolysis reactor. The reactor is an entrained flow vessel where recycled char is mixed with coal. Heated char provides the energy input for pyrolysis. The coal is heated to its decomposition temperature within one-tenth second at a reactor temperature of about 595°C (1100°F). Volatile products are separated from char by cyclones and are rapidly quenched to avoid secondary decomposition. Part of the char is transported to a char heater where the temperature of the char is raised to about 650° to 870° (1200° to 1600°F) by adding a controlled amount of air at the bottom of the heater. The heater is also an entrained flow vessel and the short residence time inhibits formation of carbon monoxide, improving process thermal efficiency. Combustion gas from the heater passes through cyclones where unreacted char is separated and returned to the pyrolysis reactor.

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*(Ref. Fig.12, App.A.)

The gases from the reactor are cooled and scrubbed to collect product tar. A portion of the gas stream is used to transport pulverized coal and heated char to the pyrolysis reactor. The rest is treated to remove acid gas and recover sulfur. The product gas can be upgraded to produce pipeline quality gas or it can be used as a hydrogen source for hydrotreating the tar product to a synthetic crude oil or a low sulfur fuel oil. Hydrotreating is carried out under pressure.

Remaining char, not passed to the char heater, can be used as a solid boiler fuel. The char is already dried and pulverized which offers an advantage over raw coal. Boiler modifications will be necessary due to the sulfur content of the char.

Major Operations and/or Modules

- Sizing and Drying
- Pyrolysis
- Product separation
- Hydrotreating
- Gas processing and sulfur recovery

Input and Output Streams

- Input Streams

  Coal
  Air

- Output Streams

  Synthetic crude oil
  Char
  Sulfur
  Pipeline gas
  Flue gas
  Tar
  Tar acids
  Waste liquids, oil, and water
  Coal dust
  Ammonia
  Blowdown and sludges from:

  - Power plant
  - Water treatment
  - Cooling tower

d. Other Systems

(1) Fischer - Tropsch System*

In 1922, Franz Fischer engaged in studies of the hydrogenation of carbon monoxide at low pressures with iron or cobalt catalysts activated by oxides of chromium, zinc, copper, and alkali metals. In 1925, at the Max Planck Institute, Franz Fischer and Hans Tropsch synthesized liquid hydrocarbons for the first time. Technical development of this synthesis was continued at Ruhrchemie beginning in 1934. The purpose, to produce motor fuel, was realized with an output of 675,000 metric tons per year in Germany from nine plants. An equal number of plants were built in other countries. Many of these plants were destroyed during World War II. Changes in the energy market discouraged continued synthesis of motor fuels from coal and the last German plant at Bergkamen closed in 1962. Because of increasing coal prices, new plants in Europe were not attractive. In addition the plants are difficult to operate, requiring much maintenance. However, in the Union of South Africa, the situation was more conducive to coal based Fischer-Tropsch Synthesis. A Fischer-Tropsch plant was constructed near Johannesburg and began operation in 1955. A second plant is now under construction in the Transvaal Region.

Major Operations and/or Modules

- Sizing. The coal is crushed, ground, and wet screened. The minimum size feed that can be used is about 6 mm. Fines, about 25 percent, are used for steam generation.

- Gasification and Gas Purification. The raw gaseous mixture formed by the reaction of coal with steam and oxygen is cooled and oil and tar are separated. The raw gas is further purified by scrubbing with methanol. The Fischer-Tropsch catalyst is very sensitive to sulfur so the gas must be treated to remove all sulfur. The hydrogen-to-carbon monoxide ratio is adjusted by the CO Shift reaction.

- Synthesis. Fresh synthesis gas combined with recycled gas is fed to the reaction zone where it mixes with catalyst. A mixture of gases, vapors, and liquids is formed. These products must be separated from the catalyst which must remain in the zone.

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*(Ref. Fig.13, App.A.)

- Product Separation. Gas and vapors separate from the heaviest hydrocarbons in the reaction zone. Cooling causes vapors to condense from the product gas stream. These liquids are sent to the refinery for separation. Part of the gas is used for recycle.

The product of the Fischer-Tropsch system is not a synthetic crude oil. It is a mixture of relatively simple hydrocarbons in a semi-refined state and is completely free of sulfur and nitrogen compounds.

Input and Output Streams

- Input Streams

Coal
Steam
Oxygen
Catalyst
Methanol

- Output Streams

Fuel gas
Propane/propylene
Butane/butylene
Gasoline
Methylethyl ketone
Light furnace oil
Waxy oil
Methanol
Ethanol
Propanol
Butanol
Pentanol
Acetone
Naphtha
Waste acids
Benzene
Toluene
Diesel oil
Tar
Creosote
Ammonium sulfate
Sulfur
Spent catalyst
Wastewater
Waste oil
Waste liquids, oil, and water

Blowdown and sludges from:

- Power generation
- Water treatment
- Cooling tower
- Gas reforming

Ash and ash conveying water

(2) Donor Solvent System*

The conversion of coal to liquid fuels by the high pressure, Bergius process was used in Germany for 15 years or more. It operates in the pressure range of 225 to 600 kg/cm^2 (218 to 581 atm.). Disadvantages of high pressure processes are the expense of high pressure vessels and of hydrogen compression. Systems operating below 100 kg/cm2 (96.8 atm), however, generally use either direct catalysis, or indirect catalysis, via a recycle solvent. Exxon is developing an indirect catalyst method. In the Exxon Donor Solvent (EDS) system, the donor solvent is prepared in a separate, fixed bed, catalytic hydrogenation step.

Prepared coal feed, hydrogen, and recycle solvent are inputs to the liquefaction area. These materials react to produce raw coal liquid, gases, and a heavy bottoms stream containing unreacted coal and mineral matter. The recycle solvent is separated from this mixture in the separation area. The solvent goes to the solvent hydrogenation area where it is regenerated catalytically. Heavy bottoms from the separation area are used to produce additional hydrogen or fuel gas in the hydrogen manufacturing area. Gas generated in the liquefaction area is used as fuel or for hydrogen manufacture. The raw coal liquids may be further hydrotreated depending on the end use. The donor solvent is prepared from the middle fraction of the coal liquefaction product which is treated by selective catalytic hydrogenation. The main function of the solvent is to provide hydrogen to free radicals formed by thermal "cracking" of coal "molecules". The solvent also carries the coal into the reactor, helps to dissolve the coal particles, and improves operability as compared to unhydrogenated solvent. The addition of hydrogen to the liquefaction step was found to reduce solvent requirements.

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*(Ref. Fig.14, App.A.)

Major Operations and/or Modules

- Sizing and Drying. Coal, bituminous or subbituminous, is dried, ground, and screened to minus 30 mesh. Prepared feed coal is supplied to the slurry preparation system. The coal/solvent slurry is metered continuously to the hydrogenation systems.

- Hydrogenation. The slurry feed stream is preheated before it enters the reaction zone. Hydrogen gas is also preheated and fed to the reaction zone, either separately or mixed with the slurry feed. Conditions for the liquefaction operation are: pressure 102 to 178 kg/cm^2 (98.7 to 172.3 atm.) temperature 370° to 380°C (700° to 715°F) solvent-to-coal ratio of 1.2 to 2.6, and residence time of 15 to 140 minutes.

- Separation. The material from the liquefaction operation consists of gas, raw coal liquids, and a heavy stream containing unreacted coal and mineral matter. The pressure on this material is decreased in several depressurizing steps. In the first step some gas and water vapor are removed. This gas is sent to the recycle gas cleanup operation for recovery of hydrogen and re-use in liquefaction.

  In the second depressurizing step more gas is released, containing heavier hydrocarbons, suitable for fuel gas. In the third step the remaining liquids and solids are heated and flashed under vacuum. This releases additional gas and vaporizes light oil containing some gas. The bottoms material contains the solids residue; i.e., unreacted coal, mineral matter, and heavy tars.

- Solvent Hydrotreating. The light vacuum gas oil, combined with other liquid hydrocarbon streams, is catalytically hydrotreated. Gaseous and liquid products from this reaction are separated. The liquid is a mixture of liquefied coal product, a heavier fraction with a higher boiling point, and a lighter fraction with a lower boiling point. The solvent fractionation operation separates the desired liquefied coal product from the higher and lower boiling fractions of the hydrotreated liquid product. Some of this mid-range solvent is recycled to the slurry preparation area and the rest is sent to product storage.

- Hydrogen Manufacture. The gas streams from the first depressurizing step and the hydrotreating area are scrubbed with monoethanolamine to remove hydrogen sulfide and carbon dioxide. If the hydrogen content is not high enough, high purity makeup hydrogen is added. This stream is then compressed and sent to the hydrogenation and solvent hydrotreating areas.

High purity hydrogen can be made from fuel gas and solids residue from the separation section.

Input and Output Streams

- Input Streams

  Coal
  Cobalt-molybdate, catalysts
  Monoethanolamine
  Water

- Output Streams

  Low sulfur fuel oil
  Naphtha
  Fuel gas
  Sulfur
  Residue
  Ammonia
  Coal dust
  Tar
  Spent catalyst
  Spent MEA
  Waste liquids, oil, and water
  Blowdown and sludges from:

  - Power plant
  - Water treatment
  - Cooling tower

(3) Methanol System*

Production of methanol from coal is a two-stage process. In the first stage, coal is gasified to produce raw synthesis gas. The raw synthesis gas contains compounds other than H_2 and CO and usually more CO than H_2. It must be treated to remove extraneous materials and the ratio of H_2:CO must be adjusted to 2:1. The clean synthesis gas is then ready for methanol synthesis. The methanol synthesis reaction is favored by high pressure, and synthesis gas from first generation gasification processes must be compressed. Other disadvantages of some first generation processes are the restriction to the use of noncaking coals, and to particle sizes greater than 6 mm (1/4 in.).

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*(Ref. Fig.15, App.A.)

The second generation gasification systems produce better quality synthesis gas requiring less treatment prior to methanol synthesis. They also operate at high pressures eliminating the need for compression.

Raw coal from storage is crushed and dried to a specific size and moisture content, depending on the type of gasification system. The coal is then preheated, if necessary, and conveyed to the gasification reactor. Steam and oxygen are injected and the coal is converted to a mixture of gases, liquids, and tars. The hot gases generated leave the reaction zone. A heat recovery system generates high pressure steam and heats boiler feedwater. Part of the steam is used in the process and the rest provides energy for product gas compression. Particulates carried out with the gas are removed by a separation system. Gas from the Lurgi gasification system requires processing to remove tars, heavy oils, and phenols. Gas from the Koppers-Totzek and Winkler gasification systems must be compressed before the ratio of hydrogen-to-carbon monoxide is adjusted to 2-to-1 by the CO shift reaction. The shifted gas is treated in an acid gas removal system to remove CO_2 and H_2S. CO_2 is rejected to the atmosphere and H_2S is further treated to recover elemental sulfur.

The purified gas goes to the methanol synthesis zone. The Lurgi process will require compression at this step. Operating conditions for methanol synthesis vary from 53 to 315 kg/cm^2 (51 to 305 atm.) and 260° to 426°C (500° to 800°F), depending on catalyst and conversion per pass desired. Higher temperatures and pressures increase the size reactions and produce lighter materials, such as ethers, and heavier alcohols in the crude methanol stream. The crude methanol from the synthesis reaction is condensed and purified by distillation. Unconverted gas is returned to the reaction zone. High, medium, and low pressure processes are available for methanol synthesis.

Major Operations and/or Modules

- Sizing and Drying
- Synthesis gas generation
- Synthesis gas treatment
- Methanol synthesis and purification

Input and Output Streams

- Input Streams

  Coal
  Water
  Air
  Oxygen
  Catalyst

- Output Streams

  Methanol
  Ash
  Coal sludge
  Wastewater
  Sulfur
  Tars
  Heavy Oils
  Tar acids
  Spent catalyst
  Coal dust
  Ammonia
  Blowdown and sludge from:

  - Power plant
  - Water treatment
  - Cooling tower

(4) Supercritical Gas Extraction System*

The solvent power of a gas or vapor increases with density and, for a given gas at a given pressure, the greatest density is obtained at its critical temperature. With proper conditions the level of supercritical extraction can be high, and increases of up to 10,000 fold in volatility of slightly volatile substances have been experienced. Therefore, if a gas or vapor is chosen having a critical temperature slightly below the temperature at which the extraction is to be carried out, it is possible to extract substances of low volatility at temperatures well below their normal boiling points. This principle has been applied to extract liquids that are formed when coal is heated. The extractant gas can be recovered by reducing the pressure of the extracted liquid vapors and, thereby, separating them in solid form.

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*(Ref. Fig.16, App.A.)

Some of the potential advantages of the Supercritical Gas Extraction (SGE) system over more conventional coal liquefaction systems are:

- No high pressure gas supply is required.
- The coal extracts contain more hydrogen and are of lower molecular weight than the products of other processes, and this facilitates their conversion to hydrocarbon oils and chemicals.
- The char or residue is a noncaking, porous product having a significant volatile material content making it ideal for gasification.
- Products separate readily from the extractant since only solid and vapor phases are involved during extraction. Filtration of a high viscosity fluid is avoided.

The process does, however, produce more char than conventional processes. Using toluene, extraction of up to one-third of the coal feed has been effected. Remaining coal is recovered as a solid. This would require that a commercial production plant would need either a market for the char or facilities to convert it into gaseous fuels. Catalytic, Inc. has developed a conceptual design and prepared a study of the economics of a plant with coal feed capacity of 10,000 ton/day.

Coal received from the mine is crushed, dried, and pulverized to 200 mesh size. The pulverized coal is fed to the extractor where it is mixed with recovered and makeup toluene and heated to about 395°C (750°F) at 100 kg/cm^2 (97 atm.) pressure. Overhead vapors consisting of toluene, extract, water vapor, and hydrocarbon gases are cooled to condense solvent and extract. Uncondensed hydrocarbons are used as fuel gases. The condensed liquid product is flashed to separate solvent toluene and water vapor as overhead and extract liquid product as bottoms. Toluene is separated from water and recycled to the extractor. Water is treated in the wastewater treatment unit. The residue in the reactor is removed mechanically, depressurized, and steam stripped to recover entrained toluene. The char can be used as fuel. The liquid extract product is fractionated to remove any remaining entrained toluene. The extract product, which is rich in hydrogen and has low molecular weight, can be readily converted to hydrocarbon oils and chemicals.

Major Operations and/or Modules

The system includes the following major operations:

- Sizing and Drying
- Supercritical extraction
- Solvent and extract recovery
- Auxiliary facilities

Input and Output Streams

- Input Streams

  Coal
  Toluene

- Output Streams

  Extract product
  Char
  Fuel gases
  Wastewater
  Flue gases
  Sulfur
  Ammonia
  Tar
  Tar acids
  Blowdown and sludges from:

  - Power plant
  - Water treatment
  - Cooling tower

2. SCHEDULES

Most of the systems discussed in this document are funded by ERDA. In some cases, ERDA is jointly funding the effort either with other agencies or with private industry. Several projects, however, are not currently recipients of federal support. In these cases, projections as to future program/project plans are not available.

Schedules for process development unit and pilot plant operations are shown in Figure 1. Only processes which have progressed to the process development stage have been included in Figure 1.

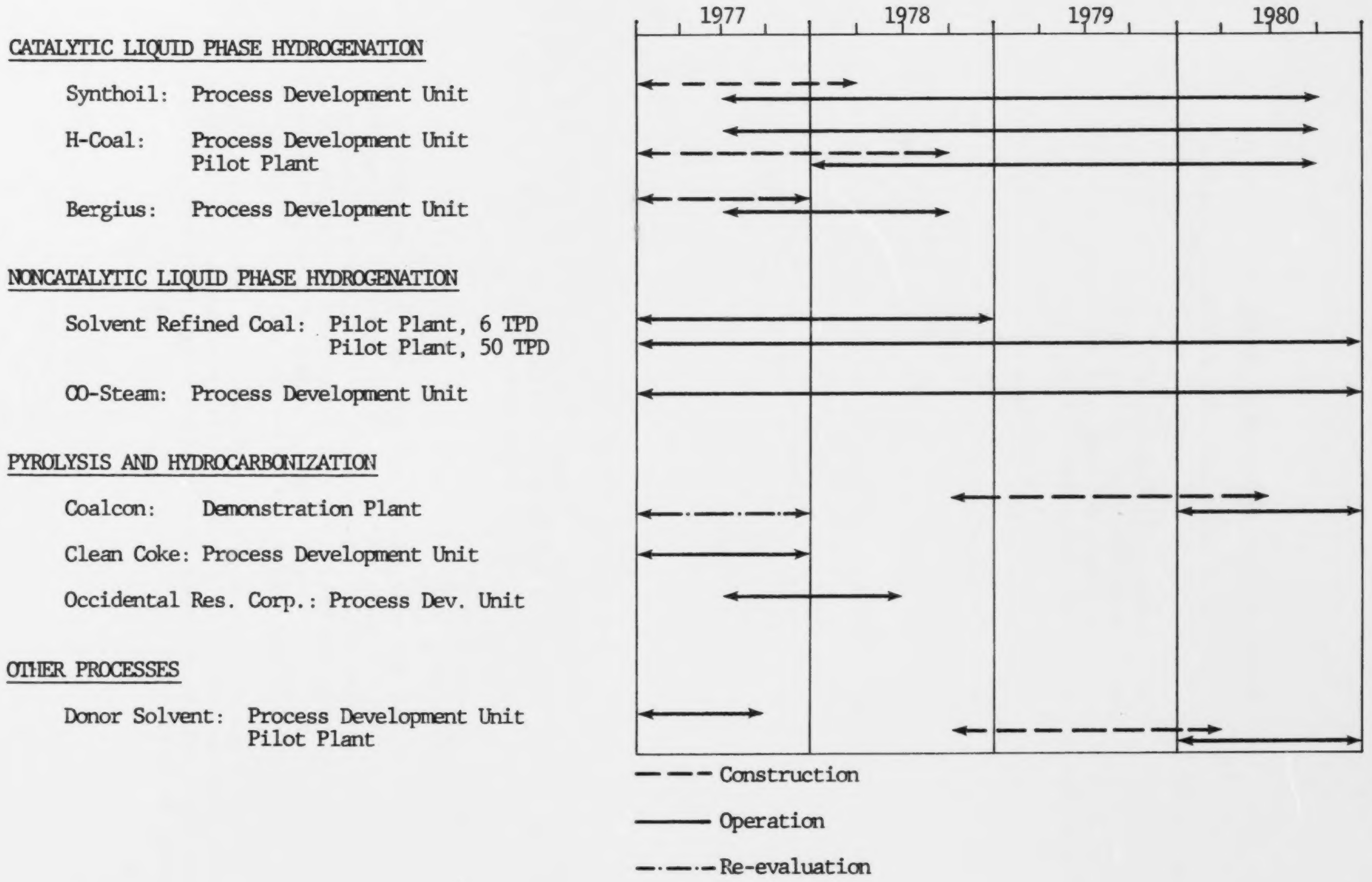


Figure 1. Process Development Operation Schedule

The two solvent refined coal pilot plants are the only liquefaction plants in operation as of December 1977. An H-Coal pilot plant, now under construction, will not be operational before the third quarter of 1978.

Brief discussions of the status of each process under development follow:

a. Catalytic Liquid Phase Hydrogenation

(1) Synthoil System

The Synthoil process is currently in the laboratory stage with construction of a process development unit underway. Operation of the process development unit is projected to begin in 1978 and continue into 1980. No firm plans for a pilot plant have been announced.

(2) H-Coal System

Based on the data obtained from the bench-scale and process development units, design and engineering of a 544-Mg (600-ton) per day pilot plant were initiated under the current ERDA contract in December 1973. The final design of the pilot plant is complete and construction is underway at Catlettsburg, Kentucky. Ashland Synthetic Fuels, Inc., Ashland, Kentucky, and Hydrocarbon Research, Inc., Morristown, New Jersey are the prime contractors. Operation is scheduled for September 1, 1978 to June 1, 1980. The plant is to be dismantled and disposed of by the end of 1980.

Ashland Synthetic Fuels will be responsible for construction and operation of the pilot plant. HRI will monitor the construction and operation of the plant to ensure that data suitable for a commercial plant design is obtained. A separate subcontractor will design the solids/liquids separation system to be installed in the pilot plant. Product characteristics will be determined and operational problems identified.

(3) Bergius System

This is the ERDA "disposable catalyst" process. Construction of a process development unit is in progress and initial operation is planned for late 1977. No pilot plant plans exist.

b. Noncatalytic Liquid Phase Hydrogenation

(1) Solvent Refined Coal System

Two pilot plants are operating. The plant at Wilsonville, Alabama will operate through 1977. A decision is to be made late in that year whether or not to continue operation. Operation of the Fort Lewis, Washington facility is planned to extend into 1981.

In addition, a demonstration plant is being considered by the Kentucky Center for Energy Research but no schedule is available.

(2) COSTEAM System

A process development unit was scheduled for completion in 1976, operation beginning in 1977 and continuing into 1981 is planned.

c. Pyrolysis and Hydrocarbonization

(1) COED System

The COED project has been completed through the pilot plant stage. Dismantling of the pilot plant has been completed. No further work is projected for this process.

(2) Coalcon System

Although originally planned for near-term construction, ERDA is considering suspension of the project due to marginal economics and technical problems with fluid-bed carbonizers. Further work is proceeding to eliminate scale-up problems involved in fluidized bed, and a decision will be made late in 1977 as to the fate of this project.

(3) Clean Coke System

Operation of a process development unit during 1977 is planned. There are no current plans for pilot facilities.

(4) TOSCOAL System

This process is not currently funded by ERDA. A facility has been tested using coal in past studies but no information on future plans is available.

(5) ORC (Garrett) System

Occidental Research Corporation (ORC) and the Commonwealth of Kentucky are in a joint venture for the purpose of preparing a detailed design for a 227-Mg (250-ton) per day pilot plant. A municipal waste processing plant of the same capacity is being constructed in San Diego County, California. ERDA's schedule calls for continued evaluation via PDU operation into Fiscal Year 1978.

d. Other System

(1) Fischer-Tropsch System

At this time, studies based on the Fischer-Tropsch synthesis are of a fundamental research nature. No concrete plans have been made yet for process development or pilot studies in this country. A second large production plant is to be constructed in the coal fields of the Eastern Transvaal region in South Africa.

(2) Donor Solvent System

Operation of the Exxon Donor Solvent process development unit is planned through 1977. Current scheduling calls for pilot plant construction to begin late in 1978 followed by operation in 1980.

(3) Methanol System

ERDA studies of methanol are directed to its use as a feedstock for catalytic conversion to gasoline.

Synthesis of methanol from synthesis gas is being planned as a commercial venture.

(4) Supercritical Gas Extraction System

This process is at such an early stage of development that no plans beyond conception have been announced.

3. STATUS

All stages of development including laboratory studies, process laboratory, process development unit, pilot plant, and demonstration plant scale projects are represented in the current status of coal liquefaction technology.

a. Synthoil System

Development of the Synthoil system, initiated by the U.S. Bureau of Mines, is currently being managed by ERDA through the Pittsburgh Energy Research Center (PERC) at Bruceton, Pennsylvania. The objective of this project is to determine the technical and economic feasibility of the process for scaleup to commercial use.

The Foster Wheeler Energy Corporation is responsible for the design and management of the construction of a 9.1 megagram (10-ton) per day process development unit to test the Synthoil process. However, recent communications from the ERDA Synthoil process Project Manager indicate that the process development unit may not be used for the Synthoil process. PERC is conducting support research for the design of the process development unit. PERC is also monitoring laboratory research on various aspects of the Synthoil process being conducted by ERDA's Sandia Laboratories and by the Argonne National Laboratory. Research on the Synthoil process is also being conducted by the Exxon Research and Engineering Laboratories and by the Battelle Memorial Institute Laboratories. These projects are being monitored by the Morgantown Energy Research Center (MERC) in West Virginia.

The initial work on the Synthoil process used a reactor with an internal diameter of 8 mm (5/16 in.) in a bench-scale plant that processed 2.3 kilograms (five pounds) of slurry per hour. Experimental testing was conducted on various coals, such as Pittsburgh seam, Indiana No. 5, Middle Kittaning, Ohio No. 6 and Kentucky strip coal. All of these types of coal were satisfactorily converted to low-sulfur fuel oil with no appreciable attrition of catalyst or loss of catalyst desulfurization activity. Other parameters investigated were hydrogen flow rate, coal content of the feed slurry, recycle rate of the product oil, hydrogen flow rate, coal content of the feed slurry, recycle rate of the product oil, and the effects of hydrogen sulfide in the recycle gas.

To demonstrate the broad applicability of this Synthoil process, a 227-kilogram (500-pounds) per day bench scale unit was constructed. This unit used a 28-mm (1.1-inch) internal diameter by 4.4-m (14.5-foot) long reactor configuration made of stainless steel. Operations were conducted on several types of coal at reactor pressures of 142 to 284 parcels (140 to 280 atmospheres) and at temperatures up to 450°C (840°F). High yields of low-sulfur and low-ash fuel oil were obtained.

Operation at the lower pressure is desirable provided an environmentally acceptable product can be made. Synthoil produced from a West Virginia bituminous coal has been analyzed, and the results were published by the Grand Forks Energy Research Center. The Hittman Associates Inc. laboratories are running analyses of: (1) the Synthoil product; (2) residue removed from the product by centrifugation; and (3) the stripping solution that had been used to remove hydrogen sulfide, ammonia, and organic vapors from the offgas vented from the process. These materials were produced from a blend of four Kentucky bituminous coals.

b. H-Coal System

The H-Coal system is being developed by Hydrocarbon Research, Inc. under the joint sponsorship of: (1) ERDA; (2) a private industry consortium composed of Electric Power Research Institute; Ashland Oil, Inc., Conoco Coal Development Company; Mobil Oil Corporation and Standard Oil Company, (Indiana); and (3) the Commonwealth of Kentucky. The overall objectives of the project are to further develop the H-Coal process and to demonstrate its technical and economic feasibility on larger scales. Specific objectives are to: (1) conduct laboratory research on all phases of the H-Coal process using the existing bench-scale unit and process development to establish design criteria; (2) design a pilot plant capable of converting 545 megagrams (600 tons) of coal per day to 318 cubic metres (2,000 barrels) per day of low sulfur boiler fuel; (3) procure equipment and materials for the pilot plant. Objective (1) is continuing. Objective (2) has been realized and the ground was broken December 15, 1976 at Cattlettsburg, Kentucky. Determination of the feasibility of commercial production of liquid hydrocarbons from coal is the objective of this ninety-million dollar pilot plant.

c. Solvent Refined Coal System

The system was originally developed by Spencer Chemical Company for the United States Department of the Interior, Office of Coal Research. Subsequently, Gulf Oil acquired Spencer Chemical Company and development continues to the present under the Pittsburgh and Midway Coal Mining Company, part of Gulf Oil.

In 1972 an all-industry group, presently consisting of The Electric Power Research Institute and Southern Companies Services, initiated a pilot plant project to study the technological feasibility of the SRC Process. Early operations were performed at fixed conditions to establish process reliability. Later operations were conducted to study the effect of process variables such as temperature, pressure, retention time, solvent-to-coal ratio, and hydrogen consumption. Operating information from this pilot plant has been used to design and build a 45.4 megagram (50-ton) per day pilot plant at Ft. Lewis near Tacoma, Washington. This project, funded by ERDA, is being developed by the Pittsburgh and Midway Coal Mining Company.

Operational data from the Ft. Lewis plant will provide opportunities for:

- Further study and development of the process.
- Accumulation of engineering and cost data for evaluation of commercial possibilities and design of demonstration or commercial plants.
- Product evaluation and market development.

The Ft. Lewis pilot plant has been in operation since October 1974. It has recently been operated to produce about 2,750 mtons (3,000 tons) of SRC which was used for functional product testing in a 22 Mw boiler.

The SRC process concept involves noncatalytic hydroliquefaction. Modifications of the SRC process include SRC-II and the Gulf Catalytic Coal Liquid Process. A process demonstration unit (PDU) using SRC technology is being operated by the University of North Dakota at Grand Forks, North Dakota, under ERDA sponsorship. The unit is designed to process one-half metric ton of lignite per day. Recent modifications at the Ft. Lewis plant now permit operation in the SRC-II mode.

In March 1972, the Edison Electric Institute and the Southern Company Services, Inc. began a joint project to study the key steps in the SRC process. Consequently, Catalytic, Inc. designed, built, and is operating the six-ton per day pilot plant. The facility was completed in August 1973. The Electric Power Research Institute (EPRI) assumed the responsibilities of the Edison Electric Institute for utility industry sponsorship in April 1973.

The pilot plant began operation in January 1974, and by the end of 1975, had been in operation for more than 7,800 hours, including periods of 45 and 75 days of sustained operation; one subbituminous and four bituminous coals have been tested. SRC products meeting plant specifications of 0.16 percent maximum ash and 0.96 percent maximum sulfur have been produced from each coal.

In January 1976, ERDA joined EPRI as a co-sponsor of the pilot plant operation. To simulate operation at the Ft. Lewis SRC pilot plant, a mixture of coals from the Kentucky Nos. 9 and 14 seams were used for plant operation. Coal feed rates as high as 75 pounds of coal per hour per cubic foot of dissolver volume, almost three times the design feed rate, were achieved. Material balance data for ten runs were obtained, allowing correlation of the results from both the Wilsonville and Ft. Lewis pilot plants. Empirical models to aid in scaling up to larger plants were developed for predicting conversion, sulfur removal, and filtration rates for operation with Kentucky Nos. 9 and 14 coals. Conversion efficiencies on an MAF basis as high as 95 percent have been achieved.

d. Donor Solvent System

Research was begun in 1966 to identify the basic Exxon Donor Solvent (EDS) system. It included studies on both hydrogenated and unhydrogenated recycle solvents. Conditions ranged from 400° to 425°C (750° to 800°F) at pressures of 2.0 to 2.5 MPa (290 to 365 psi), to 425° to 480°C (800° to 900°F) at 10 to 20 MPa (1,450 to 2,900 psi). A number of different solid/liquid separation methods were studied. Equipment was tested in an integrated pilot plant system of 454 kilograms (one-half ton) per day capacity. Techniques were developed for analyzing product and intermediate streams. Based on these studies the separation operation chosen was vacuum distillation, and a hydrogenated recycle solvent operation was selected for further development.

Studies of process variables are continuing in a 907 kilogram (one ton) per day pilot plant. It is designed to permit use of different coal feeds and to provide a variety of products.

Evaluation of several process alternatives have begun, including development of a computerized process alternative model to be used as a basic tool for the process engineering and economic studies which are planned. Engineering studies have been initiated to identify and develop equipment and engineering data needed for a safe, operable, and reliable EDS commercial plant.

The following news release was made July 28, 1977:

> "The Energy Research and Development Administration (ERDA) and Exxon Research and Engineering Company (ER&E), of Florham Park, New Jersey have signed an agreement totaling $240 million to develop a process for producing liquids from coal.
>
> The cooperative agreement calls for ERDA to fund 50 percent of the program, with the remaining $120 million provided by the private sector, according to Dr. Philip C. White, ERDA's Assistant Administrator for Fossil Energy.
>
> The Carter Oil Company, an Exxon affiliate; the Electric Power Research Institute (EPRI); and the Philips Petroleum Company have agreed to support the private sector's share of the funding. ER&E is negotiating separate agreements for the participation of EPRI and Philips. It is anticipated that other private sector firms will participate in the program.
>
> The project is based on Exxon's donor solvent coal liquefaction process, a result of independent research since 1966. The program will involve both small-scale R&D work, and the design, construction and operation of a pilot plant with a capacity of 250 tons per day. The pilot plant will be built adjacent to an Exxon refinery at Baytown, Texas. ER&E's principal coal research laboratory is located nearby. Additional laboratory and engineering will be conducted at ER&E and affiliated facilities at Linden and Florham Park in New Jersey and Baton Rouge, Louisiana.
>
> Through 1975, ER&E had spent about $32 million to formulate and develop the donor solvent process. The research, primarily at Baytown; and engineering, primarily at Florham Park, resulted in the basic process design and cost estimate for the 250 tons per day pilot plant. Additional R&D, intended primarily to confirm certain aspects of the basic design, has continued under a $12.7 million contract funded by ERDA, EXXON, and EPRI.

The new agreement runs through December 31, 1982. The project is designed to bring donor solvent coal liquefaction technology to a stage where commercial plants could be designed and built by private industry. Many of its features are based on technology already proven in the petroleum refining industry.

In the process, coal is liquefied in a non-catalytic reactor at moderate temperature and pressure. The hydrogen required for a reaction is supplied in both gaseous form and by transfer from a donor solvent. The donor solvent is an internally generated coal liquid stream which is hydrogenated in a separate catalytic reactor before being mixed with the coal feed.

The process produces liquids suitable for motor gasoline blending stocks, low-sulfur oil, and utility fuel. Liquid yields range from 2.5 to 3 barrels per ton of coal. The system produces both the hydrogen and fuel needed to sustain the process."

e. Clean Coke System

The Clean Coke system is being developed by USS Engineers and Consultants, Inc., a subsidiary of United States Steel Corporation, under the sponsorship of ERDA. The work was initiated in 1972 under the auspices of the Office of Coal Research (OCR, now a part of ERDA). The objective of the project is to design a pilot plant that is capable of converting low-grade, high-sulfur coal to low-sulfur, low-ash metallurgical coke, chemical feedstocks, and liquid and gaseous fuels.

The Clean Coke process combines coal carbonization and hydrogenation to produce solid, liquid, and gaseous fuel streams. Char produced by carbonization is converted to coke which eliminates the problem of char use and disposal. No mechanical separation equipment is used to separate the solids from the liquid product. Hydrogenation is noncatalytic and no external hydrogen is required. However, the hydrogenator operates at a very high pressure.

Laboratory and bench-scale development studies on Illinois No. 6 Seam Coal have been underway since 1969. Various aspects, including coal preparation, carbonization/desulfurization of coal in fluidized beds, and high pressure hydrogenation reactions have been the subjects of these investigations. Process development units have been built and are now operating. Two additional types of coal are scheduled to be processed. Information obtained from the process development units will be used for the design of a 218 megagrams (240 ton) per day pilot plant.

f. Bergius System

The Bergius system was one of the forerunners in coal liquefaction technology. It was used by Germany to produce aviation fuel and diesel oil during World War II. There were 18 Bergius plants producing about 4.77 Mm^3 (30 million barrels) of oil per year. The process uses catalytic liquid phase hydrogenation to produce liquid fuels. The major problem involved was the operation of high pressure solids/liquids separation equipment. The conversion efficiency was low due to the unavailability of better catalysts in the past. External hydrogen was required. Though there are no commercial Bergius plants operating currently, they have led to the recent developments in the United States of the H-Coal and Synthoil processes.

g. Char-Oil-Energy Development (COED) System

The COED system converts coal to low sulfur synthetic crude oil, clean fuel gas, and char. The oil product can be used directly as fuel oil or as a feedstock for oil refining.

Project COED was initiated in 1962 when the FMC Corporation, under sponsorship of the Office of Coal Research, Department of the Interior, started research work to upgrade coal to more valuable products. Following bench-scale studies, operation of a 45-kg/hr (100-lb/hr) process development unit was undertaken during 1965 to 1967. Western and midwestern coals were processed in a multi-stage, fluidized bed, pyrolysis system.

A small, bench-scale hydrotreating study was performed by the Atlantic Richfield Company and economic evaluations for a conceptual commercial design were made. Promising results from these preliminary studies led to the design, construction, and operation of a 32.7-Mg (36 ton) per day pilot plant at the FMC Corporation's Research and Development Center in Princeton, New Jersey. The plant was completed in August 1970, and the first successful 30 day run was made in December 1970. The pilot plant completed a number of long-term runs with good operating reliability. The plant processed about 18,144-Mg (20,000 tons) of a wide variety of American coals, including the highly caking types. Sufficient engineering data were obtained for the design of a commercial plant. All project objectives were completed, and the pilot plant was shut down in April 1975. It has since been dismantled.

The Seacoke system is a similar process, using a five-stage, fluidized bed, pryolysis process. The Seacoke products are syncrude, char, and fuel gas. The Seacoke system operates at atmospheric pressure and in the temperature range of 315° to 870°C (600° to 1600°F).

h. COSTEAM System

In 1921, F. Fischer and H. Schrader reported the use of carbon monoxide as a reducing agent in the solubilizing of coal. Interest in this discovery was lacking at that time because of low yields of heavy products and a greater interest in motor fuels. Since the late 1960s the work has been extended, modified, and improved. The process now has good commercial potential. This later work indicated the importance of using a solvent with a coal which has not been subjected to aging, drying, or oxidation. Carbon monoxide, water, and coal at 380° to 400°C (715° to 750°F) yielded a benzene soluble solid or semi-solid product. More recently work has been conducted to substitute synthesis gas for carbon monoxide and to make a product with sufficient fluidity for use as a coal slurry vehicle.

i. Coalcon System

Union Carbide has been involved in coal conversion studies since 1936. The extent of this work includes operation of several pilot plants and a fully integrated 454-Mg (500-ton) per day processing facility, which used a liquid phase catalytic hydrogenation process. The plant operated over a period of about six years in the mid 1950's. At the same time extensive research was carried out to convert coal to chemical products by pyrolysis of coal in the presence of hydrogen. The process, termed hydrocarbonization, was evaluated in a 18.4-Mg (20 ton) per day pilot plant operation. A 4536-Mg (5000 ton) per day conceptual design was made in the mid 1960's, but the economics did not favor chemical production via coal conversion and interest in the program waned.

In the early 1970's, problems with petroleum supply caused Union Carbide to re-evaluate its coal conversion experience. It was concluded that the hydrocarbonization route to convert coal to liquid fuels had potential application and a joint venture known as Coalcon was formed with Chemical Construction Corporation.

In January 1975, the Department of the Interior through its Office of Coal Research chose Coalcon to build and operate the Clean Boiler Fuels Demonstration Plant. The preliminary design phase is near completion. However, ERDA has reported that the economics are marginal and technical problems with the fluid bed carbonizer are greater than first believed. Latest reports indicate that only the design phase will be completed at this time and that additional research and development is required on the process.

j. TOSCOAL System

The Oil Shale Corporation (TOSCO), in cooperation with other private industries, has developed a process for retorting oil shale, known as the TOSCO II process. A semiworks facility was constructed at Grand Valley, Colorado to test the feasibility of the process. The capacity of this plant is 907 mton (1000 tons) per day.

The technology of oil shale retorting has been applied to the low temperature carbonization of coal. A pilot plant for processing 22.5 mton (25 tons) per day of subbituminous coal has been operating at the Rocky Flats Research Center near Golden, Colorado.

Subbituminous coal has been processed yielding a low sulfur char product of half the weight of coal with higher heating value than coal and low sulfur liquid fuel. Hydrogen generation is not required and the process uses the generated flue gases for preheating the dry coal. Hauling and transferring of hot, ceramic balls, which provide heat for pyrolysis, cause a major problem.

k. Occidental Research Corporation (Garrett) System

Garrett Research and Development (now the Occidental Research Corporation), (ORC), initiated a coal research program in 1969 to explore the feasibility of converting coal to liquid fuels. Garrett is a wholly-owned subsidiary of the Occidental Petroleum Corporation. Because of its involvement in the petroleum industry, and the fact that conversion of coal to liquid fuel then appeared more economical than its conversion to gas, emphasis was placed on a study of coal liquefaction processes. Coal pyrolysis was selected from the alternatives because pyrolysis offered the simplicity and relatively low cost needed for rapid commercialization.

The initial laboratory scale results were quite encouraging and, in 1971, a 3.6-Mg (4 ton) per day facility was constructed at LaVerne, California. Although it was built for the study of coal pyrolysis, during the first two years, it processed solid waste materials only.

During this period, a variety of solid waste feedstocks were converted to liquid fuel oil. The pilot facility began processing coal in 1974. The operation has been relatively free of problems largely due to operating expertise developed during the solid waste program. Caking and non-caking coals have been successfully tested. Based on these results, a 227-Mg (250 ton) per day municipal waste processing plant is being constructed in San Diego County.

The Occidental Research Corporation will evaluate the commercial potential of its flash pyrolysis coal liquefaction process under the sponsorship of ERDA.

The main objectives of the program are to:

- Demonstrate that caking coals can be processed continuously in a specially designed single-stage pyrolysis reactor without oxidative pretreatment, and that this method will result in a significantly higher yield of liquids than other proposed pyrolysis processes.
- Conduct extended runs in the three-ton-per-day process development unit (PDU) in order to obtain steady state heat and material balances.
- Produce and recover large quantities of the primary tar, and to evaluate methods for upgrading this material to a clean fuel or synthetic crude oil.
- Continue development of specific areas of the pyrolysis and liquids collection systems to ensure a technologically sound basis for future scale-up.
- Obtain sufficient process and environmental data for detailed design of a larger plant and conduct an assessment of the potential commercial viability of the process.

ORC and the Commonwealth of Kentucky have a cost-sharing joint venture aimed at providing a detailed design for a 250-tons-per-day pilot plant using the process.

Research and development on solid phase hydrocarbonization under an ERDA contract is underway by Rocketydne Division of Rockwell International at Canoga Park, California.

l. Fischer-Tropsch System

Interest in the synthesis of liquid hydrocarbons goes back to 1913 when patent applications described the reaction of hydrogen with carbon monoxide at high temperature and pressure and the hydrogenation of coal under pressure. In 1927, the hydrogenation of coal was undertaken on an industrial scale by I.G. Farben. This resulted from the development of catalysts with adequate activity and sulfur resistance.

A Fischer-Tropsch plant was constructed near Johannesburg and began operation in 1955. A second plant is now under construction in the Transvaal Region. It will have a consumption of 12.9 teragram (14 million tons) of coal per year.

m. Methanol System

Methanol was first produced commercially from wood. Natural gas, reformed to synthesis gas, is currently preferred for methanol production in countries where it is available as a cheap feedstock. Prior to the advent of natural gas, solid fuels had been the major source for synthesis gas for methanol production. In Europe, Asia, and South Africa where natural gas was not available, coal became the primary source for synthesis gas. In countries where economics still favor this route, methanol is produced from coal.

In the United States, natural gas is no longer readily available and alternate sources for synthesis gas are being evaluated. Abundant coal reserves present in the United States may play an important role in synthesis gas production. Technology for methanol production is available and can be updated to suit the United States' needs.

Some of the first generation processes that have been used to convert coal to synthesis gas are Koppers-Totzek, Lurgi, and Winkler. The three processes employ different features and operating conditions, and each produces a gaseous product of different composition. A number of second generation processes are under development.

n. Supercritical Gas Extraction System

Two major problems facing advancement of coal liquefaction to commercialization are operability of solid-liquid separation equipment and high hydrogen consumption. The Supercritical Gas Extraction system (SGE), now under development by National Coal Board in England seems to have solved these problems. Catalytic, Inc., a subsidiary of Air Products and Chemicals, Inc. is evaluating the technical feasibility of this process for United States coals.

4. PRIORITIES FOR FURTHER STUDIES

Initially, the types and classes of pollutants probably present in waste streams were determined. This was based on available documentation on liquefaction emissions and consideration of discharges from related industries such as coal-fired power plants and petroleum refineries.

Next, the pollution controls were evaluated to determine their capabilities and limitations. Among factors considered were:

- The types of pollutants controlled by the specific technology.
- Physical properties of the pollutants that might affect selection of controls.
- Chemical properties of the pollutants that might affect selection of controls.
- Efficiency of controls.
- Contaminants in the waste stream that could limit or prevent use of a specific type of control.
- The local environment including climate, water availability, soil characteristics, etc.

When possible, controls were matched with anticipated effluents. Specific factors needed to determine which technology was best suited were noted. These are indicated by an asterisk in the margin.

The following discussion on air, water, and solid waste controls was based upon this procedure.

a. Air Pollution Control

It is well recognized that no uniform gas cleaning method exists that will satisfy all problems and conditions. In the selection of control systems, both physical and chemical properties must be considered. The degree of efficiency of different control options also must be a basis for selection.

For example, in particulate control, coarse dust particles are separated by dry inertial separators; whereas, fine dusts, etc. require the use of fabric filters, scrubbers or electrostatic precipitators. To meet a specific level of emission, highly efficient removal systems such as precipitators are required for controlling streams with large amounts of fine particulate. Cyclones might be applicable for removal of less concentrated, coarse particles. Particulate properties basic to the performance and selection of gas cleaning equipment are particle size distribution, structure, density, composition, electrical conductivity, and agglomeration properties. Also needed to be taken into consideration are gas properties such as temperature, moisture content, total gas flow, and chemical composition. For example, particulate removal efficiency for precipitators increases with increasing sulfur content greater than two percent in the waste stream. Fine particulates will probably need a better control than now exists.

Where flares are used to control hydrocarbon emissions, a major problem is the availability of sufficient combustible waste gases to maintain combustion. The presence of trace metals in the gas stream needs to be investigated as well.

Sulfur recovery operation selection is limited by the composition of the acid gas feed stream. When the Stretford process is used, most mercaptans, carbonyl sulfides, and carbon dioxide pass through the absorber into the exit gas. Claus plant efficiency, on the other hand, requires a minimum concentration of approximately ten to fifteen volume percent of H_2S. High levels of CO_2 water vapor and hydrocarbons in the acid gas feed also reduce the efficiency.

Availability of water also can determine which control should be selected. In water-short regions, dry methods of controlling emissions should be considered.

Detailed analyses of waste stream composition and concentration combined with aforementioned properties of air pollution controls are needed to provide adequate data to select the proper control system to limit environmental impact.

b. Water Pollution Control

All process wastewater streams have different characteristics. The characteristics vary from one stream to another. For some, variations may be small, but for others a marked difference may exist. The selection of best control technology for these wastewater streams will depend on the level of information that exists for each individual stream.

The species of interest for an environmental assessment for wastewater can be divided into classes such as dissolved gases, organics, trace elements, phenols, and sulfur and nitrogen compounds. Gross characteristics such as BOD, COD, TOC, suspended solids, pH, and oil and grease of each wastewater stream are also essential.

The characteristics of wastewater streams can be used to determine the type of control technology required. It may be possible that two or more wastewater streams can be treated by a common treatment method. The variation in characteristics of wastewater streams and capability of control systems to handle such variations can be evaluated by change in the feedstock and operating variables. The concentration levels of recoverable compounds such as ammonia and phenols will determine the feasibility of recovery. Combination physical/chemical methods may serve to remove some materials such as phenols. The performance of biox systems in the presence of toxic metals is not fully known and requires evaluation.

The complete wastewater control system will be a combination of physical, chemical, and biological treatment processes. The combination sequence of the individual treatment processes will affect the degree of contaminant removal. Table 1 shows the important characteristics of wastewaters that could influence the choice of wastewater treatment and control systems.

c. Solid Waste Control

The term, bulk solid waste, includes various materials. Ash consists of a variety of metallic oxides and trace element compounds. Coal and char particles contain organic and mineral materials. Elemental sulfur may be generated as solid waste from hydrogen sulfide control technologies. Limestone sludges, primarily calcium sulfite, and calcium sulfate may be alternately generated. Zinc sulfide, the primary constituent of spent sulfur guard reactor absorbents, also may be present as will spent catalysts from applicable processes. Wastewater treatment

TABLE 1. CONTROL SYSTEMS ASESSMENT REQUIREMENTS

Control Method	Important Characteristics
Equalization	Flow variability
Neutralization	Extreme pH values
Temperature Adjustment	Extreme pH values
Nutrient Additions	Nutrient deficiency
Sedimentation	Settleable suspended solids
Dissolved air-flotation	Oils, tars, suspended solids, and other floatable matter
Activated Sludge	Organic content
Aerated Lagoon	Organic content
Oxidation Pond	Organic content
Trickling Filter	Organic content
Chemical Mixing Flocculation and Clarification	Dissolved solids, colloids, metals or precipitable organics, and emulsified oils
Dissolved Air-flotation with Chemicals	Oils, colloids, tar, and chemically coalesced materials
Activated Carbon Absorption	Trace amounts of organics and color, taste, and odor-producing compounds
Stripping	Dissolved gases, variable organics, and materials that can be chemically converted to gases

sludges, a mixture of coal tar residues, sand, coal fines, and treatment by-products may also contain untreated quantities of phenols, ammonia, cyanides, and other potentially dangerous materials.

Wastewater treatment will generate sludges requiring proper disposal. Sludge characteristics depend on the type of wastewater and the treatment method applied. It is important to identify hazardous materials that may be leached by groundwater. The volume and type of sludge will determine the disposal method that can be used. Sludge with high water content requires pretreatment. The presence of toxic materials must be assessed and positive indications will make it necessary to find control means for preventing their entry into the environment.

The discussion of solid waste component materials has been a general one, necessitated by the limited existing knowledge. Chemical analysis must be utilized to identify the specific composition of solid waste materials and to determine the concentration of these materials. The environmental impacts of these materials will need to be determined. All leachable materials present in concentrations exceeding environmentally acceptable standards must be identified.

The problems associated with disposal of solid waste must be resolved to the desired goal to minimize environmental degradation. Landfilling and minefilling techniques will require additional sophistication to confidently prevent contamination of the surrounding area. Undesirable ash constituents can re-enter the environment as a result of groundwater leaching. Little is known of the fate of landfilled trace elements, spent catalysts, or spent absorbents. Upon identification of hazardous, leachable materials present in solid waste, leaching studies will be needed to determine the available alternatives to minimize detrimental effects upon the environment. Impervious liners may be used as a physical means of preventing groundwater percolation which, in turn, prevents leaching. Chemical stabilization, to render leachable constituents insoluble or inert, may be necessary control methods in some instances. A combination of physical and chemical control methods may be the required technique.

Subsidence, the gradual settling of landfill materials, is another problem. In some cases, compaction of wastes reduces subsidence effects, allows more waste disposal per unit volume of storage space, and reduces permeability of landfilled wastes. This, in turn, reduces leaching problems, and is currently under consideration as a means of improving solid waste disposal techniques. More information is needed regarding the subsidence and compaction properties of the bulk solid wastes generated by liquefaction processes.

Although no secondary wastes are anticipated after landfilling, light hydrocarbon gases may be generated due to reaction of organic materials present. Furthermore, combustible materials may generate gases as well as cause underground fires. Unsuspected or undetected materials may undergo groundwater leaching. Periodic sampling and analysis of landfill materials and surroundings will be required to determine if secondary wastes are generated and, if necessary, to develop control technology modifications which will prevent the generation of such wastes.

B. CURRENT ENVIRONMENTAL BACKGROUND

Based on the available literature with respect to potential pollutants resulting from coal liquefaction systems and conjunctive developments, Hittman Associates has attempted to identify the classes of major organic and inorganic substances (including organometallics) emanating from gaseous, aqueous, and solid waste emissions and effluents. Division of the pollutants into the organic and inorganic (or organometallic) groups is reasonable because these two groups differ in their chemical and physical properties. These properties, in turn, influence the environmental effects of the various pollutants. The physical and chemical properties of the organics have been discussed in terms of their classes.

Two major classes of organic compounds associated with coal liquefaction systems have been identified: the aliphatic and the aromatic. Among the aliphatics, there are light-chained compounds (e.g., methane through dodecane) and all stereoisomers plus the alkenes and alkynes of the above, and the heavy-chained aliphatics. Of the aliphatic class of compounds, n-dodecane is reported to be a carcinogen.

Among the aromatic compounds are the one- and two-ring compounds: benzene (implicated in leucogenesis and Hodgkins disease); napthalenes (implicated as co-carcinogens); benzidine, and the aromatic amines known or suspected as carcinogenic; another large group of polynuclear aromatic compounds (e.g., dibenzo(a,i)pyrene, chrysene, and benzo (e) pyrene) all of which are reported as carcinogenic, and finally, the polynuclear aza-heterocyclics such as benz (c) acridine, and dibenzo(a,i)acridine, also known to be carcinogenic. Certain of the polynuclear aromatics are known to be noncarcinogenic.

While a concerted effort has been made to identify potential pollutants by classes and by discrete compounds, and further to quantify these on a multimedia basis, the reader should recognize that these data cannot be used to indicate specific impacts on plants, animals, and man at specific sites.

Information on the identity, distribution, and level of occurrence of potential pollutants throughout the entire fuel cycle and for all media is essential for the future development of guidelines, criteria, and regulatory requirements at the federal, state, and local levels. Ideally, it would be most advantageous, in this context, to establish the levels of the most toxic pollutants that would be expected _after_ use of the best treatment technologies. Desirable as this may be, the current information generally does not permit such an effort. For example, the polycyclic aromatic hydrocarbons, although composing the smallest amount of the organic load in wastewaters, are expected to have a wide range of removal efficiencies. For organics, in general, there appears to be an inverse relationship between removal efficiency and the molecular weight of the compound - the greater the number of rings, the more difficult the removal. Similarly, both microbial degradation and adsorptive sedimentation processes are highly dependent upon molecular size. Thus, microbial degradation proceeds far more slowly for the high molecular weight organic compounds, while adsorption becomes important only above the 2-ring compounds. In the multi-ring compounds, the substitution of N or S heteroatoms acts to retard microbial oxidation. Apparently, nonaromatic amines and thiophenes may be removed from wastewaters as much by volatilization during aeration as by microbial degradation. Thus, significant amounts of multi-ring aromatic compounds may pass undegraded through wastewater treatment practices known to be very efficient in removing phenols.

1. POTENTIAL POLLUTANTS AND IMPACTS IN ALL MEDIA

An effort was made to generalize on the known concentrations of about seven inorganic and twenty-two trace and heavy metal elements expected in nine major environmental compartments, (soil, rock, freshwater, seawater, air, plants, marine, terrestrial, and animals), as an aid in estimating whether the increased inputs of these elements when released in the ash, etc. from coal liquefaction, would significantly increase the level in the environment. Essentially, the same thing was done for nine major organic compounds, except that the following compartments were used: industrial and municipal effluents, natural waters, drinking water supplies, and finished drinking waters.

Estimates were made of the quantities and process discharges expected as emissions to air (organics and inorganics), as aqueous effluents (phenols, tars, benzene, etc.), as waste solids and residues (land destined wastes, sludges, etc.) and as the products of the liquefaction process, including organics and inorganics.

One of the more significant aspects of the ongoing environmental assessment effort by Hittman Associates has involved the critical analysis of natural, physical-chemical processes that effectively dissipate or enhance the toxic effects of known biological stressors in aqueous and solid waste effluents. For example, benzene, toluene, and napthalene may be volatilized into the atmosphere; whereupon they may enter the hydrosphere by various means such as washout in rain, dry deposition, or by direct diffusion into water surfaces. Such atmospheric removal is considered as contributing significantly to organic loadings in the hydrosphere. Other studies suggest that napthalene concentrates in sediment and is not readily desorbed back in the water column; further work is needed to confirm this finding. Other considerations relate to the fact that sediment adsorption is more pronounced for larger multi-ring compounds and that volatilization is most important as a removal (i.e., environmental dissipation) mechanism for the nonpolar molecules having one and two rings. Other studies suggest that polycyclic compounds may possess turnover times of months or years in soils and bottom sediments.

In the consideration of the biological cycling (bioconcentration, excretion, metabolism, and biodegradation) of pollutants resulting from coal liquefaction processes, an effort was made to assess the possible environmental fate and effects of about twelve organic compounds on microorganisms, plants, aquatic invertebrates, aquatic vertebrates, and mammals. On the basis of preliminary data, the bioconcentration factor of polynuclear aromatic hydrocarbons is reported to increase by an order of magnitude for each 50- to 60-unit molecular weight increase. Further work is required to confirm this.

The assessment of the potential impacts of coal liquefaction processes was made in terms of potential for water pollution of a facility consuming about 22,680 megagrams (25,000) tons of coal and 45,360 megagrams (50,000) tons of water each day; this would include acid drainage from coal storage piles, extensive soil erosion, and sedimentation resulting from surface mining and construction of the facility, noise, exposure of area residents to new occupational hazards, and the acute and chronic effects of low levels of pollutants released during coal liquefaction. With reference to chronic effects, interest centers on carcinogenicity, mutagenicity and, possibly, teratogencity of chemicals known to be a part of coal liquefaction and other processes. Major reliance for the foreseeable future must be placed on extrapolation from laboratory and field data on animals to man.

Present indications as to chronic effects of major pollutants, based on the study of coal-derived products, are as follows:

- Sulfur-containing constituents (in the reduced state) are present in a much greater variety and, in some cases, larger quantities than were anticipated. The ecological and health effects of reduced sulfur compounds have had little study.

- Concentrations of polynuclear aromatic hydrocarbons are very high. A detailed study of this fraction is called for to properly estimate the general threat of industrial carcinogenesis. BaP concentrations in aqueous liquors suggest an environmental hazard.

- Concentrations of weakly acidic components, suspected tumor promoters or co-carcinogens, are substantial and a wide variety occur.

- Nitrogen heterocyclics are present at substantial levels suggesting the need for additional studies. High indole/skatole concentrations suggest the possible presence of carcinogenic dibenzoacridines.

In connection with the toxicity data, it was reported that the toxicity of an ion or compound depends on the following factors: the species of test animals, the prior exposure (e.g., adaptation) of the test species, the pH, temperature, water alkalinity and hardness, dissolved oxygen level, salinity, presence of other toxicants, route of administration, and whether a static or flowing system was used. The use of acute toxicity data to predict chronic or subacute effects appears all too frequently to be based on assumptions that are highly questionable.

The toxicity of various inorganic anions and cations was reported under four headings, as follows:

- Very toxic - effects seen below 1 ppm, and the LD_{50} occurs at a dietary level of 1-10 mg/kg body weight.

- Moderately toxic - effects seen at 1-100 ppm, and the LD_{50} at the 10-100 mg/kg body weight.

- Slightly toxic - effects seen rarely in plants or microorganisms, and the LD_{50} at a dietary level of 100-1000 mg/kg body weight.

- Relatively harmless - the LD_{50} occurs at a level greater than 1000 mg/kg body weight.

Elemental cations judged "very toxic" to microorganisms included: copper, tin, silver, and mercury. Cations judged "very toxic" to higher plants included: beryllium; copper; mercury; tin; and, possibly, cobalt; nickel; and lead.

For animals, the "very toxic" elemental forms included: arsenic (III), thallium, tellurium, selenium (IV), and plutonium (IV-VI). The more toxic trace elements stressed in this report include: Be, Cr, Ni, Cu, Zn, As, Se, Cd, Sb, Hg, Tl, Sn, Co and F.

Another important effort refers to the attempt made by Hittman Associates to identify those living organisms judged by the 96-hour LD_{50}, to be the most sensitive vis-a-vis such organic pollutants as benzene, acenapthene, anthracene, chrysene, toluene, 3,4-benzopyrene-isophorone, and benzidine, among others. Organisms were identified among the marine microorganisms (algae, bacteria, etc.), fresh-water algal, terrestrial microoganisms, selected higher plants, marine invertebrates, fresh-water invertebrates, marine and fresh-water fishes, amphibians, and nonhuman mammals.

With reference to the potential health effects of various pollutants on humans, it was noted that carbon monoxide, acting on hemoglobin to form carboxyhemoglobin levels ranging from 3.0 to 6.5 percent, resulted in diminished exercise performance and diminished alertness of healthy persons. Other evidence implicating levels of carboxyhemoglobin below 10 percent have appeared to increase the risk of arteriosclerosis, impaired fetal development, and altered drug metabolism. These results are still inconclusive and suggest the need for further study. Information was also provided on the relative eye irritation potential of several hydrocarbons. It was suggested that eye and respiratory tract irritation could serve an early warning of dangerous exposure to such pollutants as n-butane, n-hexane, benzene, isopropyl benzene, and p-xylene. Among several hydrocarbons, differing in structure, 1,3-butadiene was more irritating to the eye than the multialkyl-benzenes.

One of the least studied areas relates to the additive interactions between mixtures of such aqueous pollutants as phenols, metals, ammonia, and mixtures of ammonia, phenol, zinc, copper, and cyanide. An effort was made to demonstrate more clearly the synergistic and antagonistic interactions of a number of compounds. For example, no interactions were found between phenol, ammonia, and zinc when the zinc comprised greater than 74 percent of the total predicted toxicity.

The sublethal effects of concern, both from the ecological and human health standpoints, relate to the carcinogenic and mutagenic effects by polynuclear aromatics and other organics.

Although carcinogencity in mammals is almost exclusively limited to 4-, 5- and 6-ring polycyclics and some methylated derivatives, no definite structure-effect relationship has yet been determined. Moreover, the presence of N or S heteroatoms in basic polycyclic hydrocarbon structures has been demonstrated in different cases either to intensify or lessen carcinogenic effects. Because N- and S-containing polycyclic compounds are more water-soluble than the corresponding hydrocarbons, they may be present in effluents at greater levels than those of the polyaromatic hydrocarbons; their hazards may, therefore, equal or exceed those of nonsubstituted polycyclics.

The carcinogenicity to mammals of polycyclic compounds is dramatically altered by co-exposure to other aliphatic or aromatic hydrocarbons or to phenols. Concentrations which produce effects may be lowered by several orders of magnitude when present in combination with other organic compounds. Virtually nothing is known, however, of subacute interactions between compound classes at the low levels anticipated in effluents. Potential hazards exist for both aquatic organisms and human populations exposed through either water consumption or ingestion of fish and shellfish. The scarcity of information on carcinogenic and mutagenic effects of heteroatomic polyaromatic compounds, potential interactions between compound classes and complete absence of information on effects of trace levels to aquatic organisms of all polycyclic compounds, indicate the urgent need for more research in these areas.

The following compounds are known or suspected to be carcinogenic and may be in the effluent streams of coal liquefaction plants: benzidine, nitrosamines (at 0.2 moles/kg), nickel (in the form of nickel carbonyl), chromium (especially in the form of chromic trioxide or chromate salts), beryllium (example: beryllium oxide), arsenic (example: tricalcium arsenate), selenium (example: selenide salt), cobalt (example: cobalt sulfide), lead (example: lead chromate), zinc (example: zinc chromate), mercury (example: elemental mercury), cadmium (example: cadmium sulfide), anthracenes (example: 9,10-dimethylanthracene), chrysenes (example: chrysene whose carcinogenicity is uncertain), benzanthracenes (example: benzo(a) anthracene), fluoranthenes (example: benzo (j)), fluoranthene and benzo(b) fluoranthene, cholanthrenes (example: 20-methylcholanthrene), benzopyrenes (example: benzo(a)pyrene), dibenzopyrenes (example: dibenzo(a,h)pyrene), mono- and dibenzacridines (example: dibenz(a,h)acridine), benzocarbazoles (example: 7H-benzo(c)carbazole), dibenzocarbazoles (example: 7H-benz(c,g)carbazole), benzanthrones (example: 7H-benz(d,e) anthracene-7-one), aminoazobenzenes (example: 4-dimethylaminoazobenzene), and naphthylamines (example: alpha-naphthylamine.

The chemical composition of products from coal-liquefaction systems suggests that they will exhibit considerable carcinogenicity. Benzo(a)pyrene concentrations ranged from 40-50 ppm in coal-derived products as compared to 1 ppm for carcinogenic condensed tobacco smoke. Concentrations of

PAH are usually 10-100 times the level found in smoke; and compounds of known tumor-initiating, tumor-promoting, and co-carcinogenic activity, such as pyrene and alkalynaphthalenes are present. Chromatographic surveys of gaseous and aqueous samples associated with conversion processes further illustrate the existence of a potential environmental and/or health threat. Gaseous samples from one process were found to contain considerable concentrations of H_2S, COS, thiophene, and methyldisulfide. An aqueous separator liquor from one process contained sulfur-bearing constituents, phenolics, and a measurable (ppb) concentration of benzo(a)pyrene. A stack gas sample from one process was found to contain at least fifty low molecular weight organic compounds.

In the absence of medical data, compounds with boiling points above 250°C should be handled with caution. In general, these are the compounds with the higher molecular weights, large number of aromatic rings, lower water solubility, and higher potential for relative persistence and bioaccumulation in organisms.

2. FEDERAL/STATE STANDARDS, CRITERIA

Consistent with the objective of evaluating coal liquefaction systems, a review of existing environmental requirements was made at the federal and state government levels. The study of state laws was restricted to those states which have the demonstrated coal reserves necessary to provide sites for commercial coal liquefaction facilities in the near and far term. The states which have been addressed are: Alaska, Arizona, Colorado, Illinois, Indiana, Kentucky, Montana, New Mexico, North Dakota, Ohio, Pennsylvania, South Dakota, Texas, Utah, West Virginia, and Wyoming.

The major conclusion of the review is that no legislation currently exists directly pertinent to coal liquefaction systems. Prior to commercialization, such legislation is needed at the federal, state, and local levels. A review of existing standards and guidelines does provide an idea of long-range goals in the area of environmental policy. Additionally, existing standards governing related fossil fuel technologies could serve as the foundation on which standards for liquefaction facilities will be based. However, at this time it is impossible to project how stringent and how comprehensive environmental regulations will be specific to commercialized coal liquefaction systems.

a. Federal Policy

The Clean Air Act outlines existing federal policy concerning air quality standards that have been established for several types of emissions, including: particulates, hydrocarbons, and sulfur oxides. These standards are summarized in Table 1 of Appendix B.

Additionally, standards for new sources have been established. Specifically, the standards for coal preparation, plants, petroleum liquid storage vessels, and fossil fuel-fired steam generators may be similar to the standards which will be established for corresponding areas of coal liquefaction facilities. The steam generator data may be more applicable to production utilization than it is to production. Possibly applicable new source standards are discussed in Table 2 of Appendix B.

National emission standards for air pollutants deemed hazardous are established in conjunction with the Environmental Protection Agency (EPA). Currently, standards exist for mercury, beryllium, and asbestos. Although none of these are likely to affect coal liquefaction, future standards for hazardous air pollutants may be applicable.

The Federal Water Pollution Control Act has established long-range national goals to limit point source effluent concentrations. The act requires "application of the best practicable control technology currently available" not later than July 1, 1977. Six years later, "application of the best available technology economically achievable" will be required to meet the national goal of "eliminating the discharge of all pollutants."

Effluent guidelines and standards exist for several industries which have operations similar to those proposed for liquefaction plants. Table 3 of Appendix B includes standards and guidelines for coal preparation and storage facilities and coking operations. Coking operations are more directly applicable to liquefaction processes based on pyrolysis. In addition, a comprehensive system of standards has been established for petroleum refinery operations. Effluent limitations for refineries are functions of overall refinery size and the capacities and pollution potentials of the refinery unit processes. A similar system may be developed for liquefaction plants, the factors of plant size and process type making the effluent limitations as equitable as possible.

The characterization of solid waste materials leaving coal conversion plants is incomplete. It is possible that hazardous wastes are present. For this reason, subsequent discussions of solid waste disposal shall include hazardous waste disposal, although the necessity of such measures is not certain.

The Resource Conservation and Recovery Act of 1976 replaced the Solid Waste Disposal Act as a statement of National Solid Waste Policy. Guidelines for landuse and ultimate disposal of solid wastes are not as advanced as the legislation governing emissions to air and water. The most applicable EPA requirements and recommendations are described in Table 4 of Appendix B.

Not all constitutents of the products, by-products, and wastes generated by the liquefaction process are known. The Toxic Substances Control Act was established to provide regulation and testing of new and existing materials which could cause unreasonable health and environmental consequences. Testing may be prescribed for cumulative or synergistic effects, carcinogenicity, mutagenicity, birth defects, and behavioral disorders. Should any liquefaction process components be characterized as toxic, the development of technology capable of isolating and disposing of those components will be necessary. The potential impact is difficult to assess because of incomplete characterization of process components and incomplete determination of substances and concentrations of those substances which should be considered toxic.

b. Selected State Policies

- Alaska. Ambient air quality standards and standards for industrial process emissions have been established. Table 5 of Appendix B shows the standards and reference conditions. Emissions standards for industrial processes are described in Table 6 of Appendix B.

Water quality parameters are dependent on water uses, which range from potable water to industrial water. Table [illegible] of Appendix B defines the standards required for various parameters such as pH, dissolved organics, etc. for these water use classifications.

Regulations for the management of solid waste are directed primarily toward municipal wastes rather than those of an industrial nature. Should leaching or permafrost prove a problem, special disposal procedures must be submitted to the Department of Environmental Conservation. A minimum of two feet of earth must be maintained between solid wastes and the anticipated high groundwater table. Surface drainage must be prevented from contacting the landfill area. Solid waste may be landfilled in layers of not more than two feet prior to compaction.

- Arizona. In addition to ambient air quality standards, Arizona has source emissions standards for particulates, sulfur compounds, and volatile organic compounds. These values are presented in Tables 8 and 9 of Appendix B. State goals for ultimate achievement have also been established; they are included in Table 8 of Appendix B.

  Water standards are established for surface waters with specific uses. Applicable standards for domestic and industrial waters are compiled in Table 10 of Appendix B.

  Solid waste legislation lags the other areas. Daily landfill cover up 6 to 12 inches are required. Final cover must be a minimum of two feet deep.

- Colorado. Colorado has enacted standards of performance for new stationary sources. Of these, the standards of performance for petroleum refineries are probably most indicative of future legislation. These standards are reviewed in Table 11 of Appendix B. Of particular interest is Colorado legislation pertaining to oil-water separators. Several liquefaction processes, including currently operating solvent refined coal (SRC) pilot plants use similar equipment. One or more of the following vapor loss controls is required: a solid cover, a floating roof, a vapor recovery system, or special equipment which can demonstrate equal or superior efficiency.

  Both effluent limitations and water quality standards have been promulgated. As Table 12 of Appendix B shows, the standards are very stringent for all classes of water. Effluent limitations are also presented in Table 13 of Appendix B. Solid waste requirements are not as rigorous. Compaction of wastes is required.

- Illinois. Environmental legislation in Illinois is among the most comprehensive of all the states considered. Both air quality standards and stationary sources standards have been promulgated. Table 14 of Appendix B describes air quality standards. Those emissions standards which are most applicable are discussed in Table 15 of Appendix B.

  Illinois water quality standards are dependent upon water use classification. Lake Michigan is treated as an independent classification. Effluent standards also exist. A mixing zone of a circle of a 600 foot radius is allowed when quality standards are more stringent then the corresponding effluent standard. Table 16 of Appendix B summarizes the applicable standards for water quality, and Table 17 of Appendix B highlights applicable effluent standards.

Disposal of hazardous wastes must be authorized by permit. No hazardous waste regulations are specified. Also, noise control legislation exists which might effect plant operations. The levels of allowable sound are discussed in Table 18 of Appendix B.

- Indiana. In addition to ambient air quality standards (Table 19 of Appendix B), Indiana has laws controlling the storage and handling of volatile hydrogen liquids. A vapor recovery system, floating roof or alternative system which meets approval of the proper state agencies is required. Volatile organic liquid-water separators require either a solid cover or one of the previously discussed vapor control methods required for storage systems.

Indiana water quality standards state criteria to be considered in determining a mixing zone but prescribe no absolute zone, reasoning that too many variables are involved. Pertinent water quality criteria are outlined in Table 20 of Appendix B.

Prior to the issuing of permits to operate landfills, a detailed plan of the operation must be submitted to, and approved by the appropriate state agencies.

- Kentucky. Air quality standards are listed in Table 21 of Appendix B. Note that Kentucky has a standard for hydrogen sulfide as well as sulfur dioxide. The standards of performance for petroleum refineries have been compiled in Table 22 of Appendix B.

Kentucky water quality standards vary with stream use classification. Table 23 of Appendix B shows the most stringent standards, which would be applicable in a multiple-use situation. Solid waste requirements include providing more than two feet of compacted soil between solid waste and maximum water table, two feet or more of compacted earth between solid waste and bedrock, solid waste layers of two to three feet, and a final daily cover of six inches to prevent waste dispersion. A final cover of two feet of compacted soil is required to be followed by revegetation.

- Montana. Montana has adopted the federal new source performance standards to supplement its own ambient air quality standards. Applicable ambient standards are presented in Table 24 of Appendix B.

Water quality policy consists of general water quality criteria and specific water quality criteria which correspond to the various water-use classifications. Table 25 of Appendix B describes criteria for the most and least stringent classifications to give an idea of the range of conditions permitted.

Site approval is required for solid waste disposal when hazardous wastes are involved. Daily cover of six inches and final cover of two feet or more are also required. Disposal sites shall not be located near springs or other water supplies, near geologic formations which could cause leaching problems, in areas of high groundwater tables, or within the boundaries of 100 year flood plains.

- New Mexico. New Mexico is presently the only state that has promulgated emission standards applicable to coal conversion facilities; specifically, coal gasification plants. Stacks at least ten diameters tall, equipped with enough sampling ports and platforms to perform accurate sampling, are required. Particulate emissions requirements exist for briquet forming areas, coal preparation areas, and the gasification plant itself - with an additional requirement for gas burning boilers. Limits have been placed on dischargeable concentrations of sulfur, sulfur dioxide, hydrocarbons, ammonia, hydrogen chloride, hydrogen cyanide, hydrogen sulfide, carbon disulfide, and carbon oxysulfide as well. These limits are compiled in Table 26 of Appendix B.

There are stringent criteria, relative to most of the states reviewed. However, a review of New Mexico air laws pertaining to petroleum refineries reflects an interest in environmental preservation, not a distrust of new technology. Emissions standards for ammonia and hydrogen sulfide, for example, are the same for both industries. In fact, refineries have additional limits on mercaptan and carbon monoxide not presently included in gasification legislation. These requirements, as well as New Mexico Ambient Air Quality Standards are presented in Table 27 of Appendix B. The ambient air criteria for heavy metals and the difference in dischargeable carbon monoxide concentrations between new and existing refineries should be noted. Water quality standards are very specific. For example, the Rio Grande Basin is divided into fifteen sections, each with independent water quality standards. Table 28 of Appendix B presents applicable water quality criteria for selected areas.

Solid waste regulation is not as advanced or as complicated as corresponding air and water controls. State requirements include six inches of daily cover, compaction of wastes to smallest practical volume, and a minimum final cover of two feet of earth. Landfill bottoms must be a minimum of 20 feet above groundwater level.

- North Dakota. Table 29 of Appendix B describes applicable ambient air quality standards of North Dakota. These have been established in accordance with the state air quality guidelines which call for preservation of the health of the general public, plant and animal life, air visibility, and natural scenery. The guidelines also require that ambient air properties not change in any way which will increase corrosion rates of metals or deterioration from industrial processes. For particulates, the equation governing process industries in Arizona is the same for North Dakota. Sulfur dioxide emissions are limited to three pounds per million Btu of heat input.

Water quality is dependent upon water classification. Applicable criteria for Class I waters are discussed in Table 30 of Appendix B. Mixing zone guides are described in preference to defining a mixing zone applicable to every situation.

North Dakota regulations specify a daily cover of six inches and a final cover of twelve inches for sanitary landfill operations.

- Ohio. Ohio legislation to preserve air quality includes both ambient and emission standards. Ambient standards are in Table 31 of Appendix B. Emissions regulations for industrial processes which might be applicable have been promulgated for particulates, sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and photochemical oxidants. Additionally, priority zones have been established. These zones do not presently meet EPA standards for sulfur dioxide, nitrogen dioxide, and particulates. The sulfur dioxide and particulate emissions limits are mathematical functions of total emissions discharged, and process throughput, respectively. Carbon monoxide from petroleum refinery processes must go through an afterburner prior to discharge. Standards for storage of hydrocarbons are in line with those previously mentioned. Photochemical oxidants must be incinerated to a minimum of 90 percent oxidation prior to discharge to the atmosphere.

Effluent discharge requirements are variable. Water quality standards depend on water-use and mixing zone, which are formulated for specific discharges and locations, rather than a generalized definition. Criteria for public water supply, the most stringent classification, are highlighted in Table 32 of Appendix B. Dissolved oxygen and pH levels for streams supporting aquatic life are included. Table 33 of Appendix B describes general standards.

Plans for all sanitary landfill sites and operations must be approved in advance. A complete description of site terrain and subterrain must be specified as well as soil chemistry and local hydrology data. A six-inch daily cover and a two-foot final compacted soil cover are also required. Semi-annual well monitoring for chlorides, chemical oxygen demand, total organic carbon, and total dissolved solids is an additional requirement.

- Pennsylvania. Hydrocarbon emissions are limited by controls requiring either a vapor recovery system or floating roof for storage tanks; the former required for hydrocarbon loading equipment, the latter for hydrocarbon-water separators. Applicable ambient standards are shown in Table 34 of Appendix B. Standards for particulate emissions are included in Table 34.

Pennsylvania water quality criteria, based upon water use are in Table 35 of Appendix B. Applicable criteria are given for the Monogahela River, as specific criteria are different for each stream and, in many cases, different for sections of the same stream.

The solid waste legislation of Pennsylvania is among the most evolved of any of the states considered. In addition to the general solid waste discussions of most states, Pennsylvania has promulgated rules and regulations governing coal refuse disposal. The rules prohibit disposal which will promote fire, subsidence, or leaching problems. The state has also published a statement of guidelines and acceptable procedures for the operation of such disposal areas. Generally, two feet of final cover is required. The landfill shall be a minimum of six feet above the seasonal high water table. Disposal cells may not exceed eight feet with compacted solid wastes layers of two feet or less. Hazardous waste disposal plans must be approved by the appropriate state agencies.

- South Dakota. The ambient air quality standards of South Dakota are shown in Table 36 of Appendix B. South Dakota has reserved the right to set emissions standards for any source which may be exceeding the ambient standards. Standards for fuel burning installations and general process industries are listed in Table 37 of Appendix B.

Water quality criteria for three types of waters are presented in Table 38 of Appendix B. It is obvious that the intended water-use provision of several state laws, including South Dakota, will be an important point to consider in site selection for commercialized coal conversion facilities. Mixing zones are dependent on stream characteristics. Lakes are not allowed a mixing zone.

South Dakota solid waste regulations are in line with those of the states previously mentioned with regard to operations. Of greater interest are the requirements pertaining to site locations. Landfills are not permitted within 1,000 feet of any lake or pond, or within 300 feet of any stream or river. Also, a minimum of six feet between waste and groundwater table must be preserved. Such requirements, promulgated specifically to prevent leaching to groundwater, may provide an applicable basis for future regulatory control of disposal of solid wastes from liquefaction processes.

- Texas. All national primary and secondary ambient air quality standards are applicable in Texas. An additional ambient standard for inorganic fluoride compounds, specifically hydrogen fluoride gas, has also been promulgated. This standard, along with net ground level concentrations for applicable compounds, is presented in Table 39 of Appendix B. Emission rates for particulates and sulfur dioxide have been promulgated; both are functions of effective stack height. Additional emission concentration limits for particulates, sulfur dioxide, and nitrogen oxides in fossil fuel burning steam generators are also discussed in Table 39. Visibility requirements prohibit exceeding 20 percent opacity, 15 percent for stationary flues with total flow rates exceeding 100,000 acfm. These opacity limits are for five minute periods and do not include opacity due to uncombined water mists.

Texas water standards consist of three parts: general criteria, numerical criteria, and water uses. The latter two are highly specific, similar to the Pennsylvania legislation. Water quality parameters and uses for the San Antonio River Basin are shown in Table 40 of Appendix B. It should be noted that Texas has one of the warmest climates among those states considered. Water temperatures may naturally exceed 96°F. For this reason, the 90 degree maximum temperature suggested by the National Technical Advisory Committee is not applicable. A maximum temperature increase of 3°F (1.7°C) is permitted for fresh waters, and 5°F, (2.8°C) for saline waters.

Three classifications of industrial solid waste exist. These can be characterized as: hazardous, naturally decomposable organics and inorganics, and inert materials. All plans and specifications relevant to site selection, design, and operation of industrial waste disposal operations must be reviewed and approved by appropriate state authorities.

- Utah. Utah has no ambient air or new source standards at this time. Current federal standards are applicable. The Utah Air Conservation Regulations note that the Utah Air Conservation Committee and the State Board of Health do not agree with most of the federal standards. There is no indication of the types of standards these organizations favor. Future legislation will have to answer that question. State emissions standards have been set for particulates requiring 85 percent control. Sulfur emissions must meet federal ambient and new source standards.

Stream quality criteria are dependent upon stream classification. Class "A" waters are, without pretreating, to be suitable for a variety of uses including domestic water supply and propagation of fish and wildlife. Such waters are to be free from organic substances measured by biochemical oxygen demand. A pH range of 6.5 to 8.5 is to be maintained. Physical characteristics and chemical concentration standards are the same as prescribed by "Public Health Service Drinking Water Standards, 1962." These are described in Table 41 of Appendix B. All solid waste disposal operations must meet approval of the Utah State Division of Health.

- West Virginia. A brief review of West Virginia state air laws provides a good idea of the relative importance of the coal mining industry there. Air pollution control legislation has been promulgated for refuse disposal, preparation, and handling operations. These regulations and particulate limits for manufacturing process operations are detailed in Table 42 of Appendix B. Ambient air quality standards are detailed in Table 43 of Appendix B.

Water quality criteria, based on water use similar to the Pennsylvania criteria are highlighted in Table 44 of Appendix B. Criteria for the Gauley River and tributaries were chosen for presentation due to the fact that it is acceptable for all water use classifications.

West Virginia has three solid waste classifications, analagous to those previously described in the Texas solid waste laws. Requirements for disposal of wastes of a hazardous nature shall be determined on a case-by-case basis. Class II decomposable wastes are subject to six inches of daily cover and two feet of final cover.

- Wyoming. Table 45 of Appendix B defines the state ambient air quality standards. Emissions standards, primarily applicable to fossil fuel burning installations, are presented in Table 46 of Appendix B. Wyoming has additional regulations governing hydrocarbon storage and handling. Waste disposal combustion systems for vapor blowdown or emergency situations are to be burned in smokeless flares. Pressurized tanks, floating roofs of vapor recovery systems, are required for storing hydrocarbons.

Water quality standards which may impact future liquefaction operations are summarized in Table 47 of Appendix B. Wyoming waters are classified as having potential to support game fish (Class I), potential to support nongame fish (Class II), or as not having the potential to support fish (Class III). In addition, waters designated as part of the public water supply must meet the most recent Federal Drinking Water Standards. These are described in Table 48 of Appendix B.

The Wyoming Department of Environmental Quality reviews construction and operating plans of all industrial or hazardous waste disposal operations. Industrial waste disposal sites shall not be located in areas of low population density, land-use value, and groundwater leaching potential. Monitoring wells must be installed prior to commencement of operations. Disposal sites may not be located near drinking water supply sources. It is suggested, but not required, that disposal sites with impermeable soil be selected.

3. OTHER REGULATORY REQUIREMENTS (NEW OR PENDING)

In order to maintain a data base of existing environmental requirements directly and indirectly applicable to coal liquefaction processes, references such as the Environment Reporter must be reviewed periodically. Also, in addition to new and pending legislation, a keen awareness of new developments which may affect future legislation is necessary. This section discusses recent developments which could directly or indirectly influence future policy regulatory coal liquefaction processes.

One change is in the legislation governing coal preparation facilities, essential to all liquefaction processes. Previously, coal preparation facilities were subject to zero-discharge effluent limitations. Instead, EPA revised the regulations and coal preparation plants are now subject to the same effluent limitations as the coal mining point source category, with different effluent concentration analogous to those for alkaline and acidic mine drainage.

Appreciable quantities of benzene, toluene, and xylene and their derivatives (BTX) are presumed to be generated by all liquefaction processes. EPA has recently identified benzene as a hazardous air pollutant under the Clean Air Act. Benzene exposure has been linked to leukemia by studies conducted by the National Institute for Occupational Safety and Health (NIOSH). The Occupational Safety and Health Administration (OSHA) has advocated reduced exposure levels in the workplace. While no standards have been established at this time, EPA has made a tentative statement that benzene emission levels would impact petroleum refining and coke oven operations, which implies a possibility of impacting coal liquefaction operations.

Recently, the Environmental Defense Fund (EDF) petitioned EPA to list arsenic as a hazardous air pollutant under the Clean Air Act, citing reports by the National Academy of Sciences and NIOSH which link arsenic to skin and lung cancer. Shale oil, petroleum refining, and coal combustion are all sources of arsenic emissions to the atmosphere. Coal combustion accounts for 12 percent of all arsenic emissions. Should arsenic emission levels be established, they may impact coal liquefaction as well as other fossil fuel processing industries.

Another development is a report by the National Academy of Sciences (NAS) which warns that continued use of fossil fuels as a primary energy source for more than 20 to 30 more years could result in increased atmospheric levels of carbon dioxide. The greenhouse effect and associate global temperature increase and resulting climate changes could, according to NAS be both "significant and damaging." The findings, although not conclusive, demonstrate the need for positively identifying the long-range effects of using fossil fuels to provide energy needs. The impacts on coal utilization for energy, including coal liquefaction, are obvious. For this reason, the Energy Research and Development Administration (ERDA) established a research office to assess the possible environmental effects of increased levels of carbon dioxide in the atmosphere. As well as conducting its own research, the office will function as a central contact point for other scientific research organizations and government agencies.

C. ENVIRONMENTAL OBJECTIVES DEVELOPMENT

1. CRITERIA FOR PRIORITIZING

In conjunction with the development of Environmental Characterizations, an effort was completed to establish priorities for the development of coal liquefaction technologies and control needs. The candidate systems were those most advanced from a development standpoint and those considered to be of possible interest to commercial developers and industrial users. The criteria selected follow:

- Stage of Development
- Schedules for Construction, Development, etc.
- Potential for Emissions
- Process Similarities
- Resource Conservation
- Potential Hazard of Residual Emissions
- Impact/Use Potential
- Quantity of Residual Emissions
- Rate of Availability, i.e., how fast can the technology be brought to commercial use?
- Energy Efficiency
- Priorities for Construction, Development, etc.
- Demonstrated Scale of Production
- Probability of Success in Development
- Projected Process Development Costs
- Applicability, i.e., extent of projected markets

All available information concerning the criteria was assembled for all processes. Each system was then assigned a relative value with respect to each criterion. When it was possible to define an ideal situation, points were awarded on the basis of a fractional approach to the ideal. In other cases, only relative comparisons were possible.

The point values were then totaled vertically for each criterion and normalized. For each process, the normalized values were totaled, horizontally, to establish the prioritized rankings. the greatest number of points being assigned the No. 1 ranking. The result is a comparative rating and evaluation of the systems established on the basis of projected needs for detailed study and environmental characterization. The order of ranking for the candidate systems in coal liquefaction technology is as follows:

- Solvent Refined Coal
- H-Coal
- Exxon Donor Solvent
- Synthoil
- COED
- COSTEAM
- Clean Coke
- Fischer-Tropsch
- ORC (Garrett)
- Coalcon
- Methanol Synthesis
- Toscoal
- Bergius

This ranking has served as an initial guide; however, the ranking system is undergoing further development as discussed in the next section.

2. METHODOLOGIES BEING DEVELOPED

IERL-RTP is currently developing an environmental assessment methodology especially related to the Federal Interagency Energy/Environment R&D Program in support of standards development. The environmental assessment methodology will consist of various methodology components being developed with the assistance of participating contractors. One such specialized component is the development of process assessment criteria which will be used to set priorities with regard to the selection of systems for further study in environmental assessment. Hittman Associates' task, called Process Assessment Criteria, consists broadly of:

- delineating criteria to be considered in evaluating systems (to set priorities for further study),
- assigning these criteria a normalized set of relevance weights, based on a rational decision analysis method, and
- preparing step-wise instructions which will permit application of this methodology component for a generalized environmental assessment.

Environmental assessment is defined as a continuing, iterative study at: (1) determining the comprehensive multimedia environmental control costs, from the application of the existing and best future definable sets of control/-disposal options, for a particular set of sources, processes, or industries; and (2) comparing the nature of these loadings with existing standards, estimated multimedia and environmental goals, and bioassaying specifications as a basis for prioritization of problems/control needs and for judgement of environmental effectiveness.

In developing the generalized methodology, the effort was focused on several elements:

Criteria Identification. A set of measurable factors was identified which, together, could be used to determine quantitatively the need for immediate further attention to systems being considered for a generalized environmental assessment. These measurable factors characterize the timing, general nature, magnitude, and likelihood of commercialization and potential environmental degradation resulting from subject systems. Also, with the knowledge that a criteria weighting process would be applied, it was attempted to ensure that all significant criteria were listed and that overlap between criteria was minimized.

Criteria Weighting Factors. A decision model was used to apply the judgement of knowledgeable individuals to the generation of weighting factors quantifying the relative importance of the criteria. The procedure was repeated as necessary for subcriteria under each criteria. The decision model used was DARE (Decision Alternative Rational Evaluation).

Use of Weighted Criteria. Generalized instructions were prepared to guide Process Assessment Criteria users in applying the weighted criteria to actual systems. These instructions addressed the quantification of each criterion for candidate systems and the procedure for applying the given weighting factors to those criteria to obtain total Process Assessment Criteria scores. These instructions are integral to the complete DARE decision-making process. The DARE-derived scores may be used to rank order, choose subsets, or otherwise prioritize candidate systems for an environmental assessment.

Work on Process Assessment Criteria is continuing.

D. ENVIRONMENTAL DATA ACQUISITION

1. EXISTING DATA FOR EACH PROCESS

Generally, the data pertinent to definition of environmental effects of coal liquefaction systems fall into one of two categories:

(1) What are the discharges to the environment from coal liquefaction facilities?

(2) What effects will these discharges have on the environment?

Since there is no commercial-sized coal liquefaction facility in the U.S. today, answers to both questions are conjectural at this time.

The best-known historical use of coal liquefaction technology occurred during the World War II era when Germany produced commercial quantities of aviation gasoline using the Bergius process. Under these circumstances, a study of environmental discharges and effects would be expected to have low priority. Also, coal liquefaction technology has changed and improved to such an extent that most of the existing data would be of little environmental usefulness.

During the period after World War II, various coal liquefaction processes were investigated, but were abandoned as being uneconomic to compete with petroleum and natural gas fuel sources. Data on environmental discharges and effects for these systems are sparse. Bench-scale and pilot plant investigations were designed to solve technical process problems and did not usually include much treatment/control technology equipment.

It was not until the late 1960's and early 1970's that economics of coal liquefaction were reviewed and efforts again started on various process developments. Again, however, investigations have been centered on solving technical process problems and do not usually include much treatment/control technology developments.

Existing data for the environmental discharges on the different systems are fragmentary and usually may be characterized as:

- Product and waste descriptions based on hydrocarbon chain length, boiling point ranges, viscosities, and element contents (sulfur, nitrogen, carbon-hydrogen ratios, metals, etc.)

- Qualitative analysis for specific organic compounds, often for known carcinogenic effects.
- Out-of-date and/or partial quantitative analysis of products.

Since there are no available overall quantitative analyses of product and waste discharges from any existing coal liquefaction system, Hittman Associates is currently preparing reports which will provide a preliminary estimate of such discharges for four processes - Solvent Refined Coal, Synthoil, H-Coal, and Exxon Donor Solvent. Input-output materials characterizations for these reports are described in subsection D-4. In addition, sampling and analytical techniques and a test program development for future definition of environmental discharges are described in subsections D-2 and D-3, respectively.

Environmental effects for coal liquefaction facilities may be expected from:

- Atmospheric emissions of particulates, sulfur and nitrogen compounds, and other volatiles.
- Wastewater contaminants such as: acids, phenols, organics, cooling tower chemicals, and inorganic compounds.
- Solid and residue streams such as: ash, still bottoms, char, spent catalysts, and filtered solids.
- The products.

Most of the existing data for environmental effects are for the product, or the solid and residue wastes.

There is voluminous information on the presence of biologically active organic (carcinogenic, etc.) compounds in the products. Since most of these organic compounds are formed in the hydrogenation step of the process, they could be found throughout the plant as a result of leaks, spills, and other sources of contamination. Considerations of the biological activity would also have to be given during handling, transportation, storage, and use of these products. Hittman Associates is currently preparing an environmental characterization report which will discuss the literature and other available data on the environmental effect of the products from coal liquefaction systems.

In addition to the products, biologically active and toxic pollutants have been identified in the solid and residue wastes and wastewater contaminants. Since most of the hazardous organics and inorganics from the coal liquefaction process are relatively nonvolatile, they may be expected to be present in the solid and residue wastes. Limited data on still bottoms have shown that biologically active organics are present. Analysis of ashes show that metals and metallic compounds are concentrated in this process waste. Phenols and organics have been similarly identified in the wastewater.

Although the presence of biologically active and toxic substances in the products and process wastes have been documented, the environmental effects have not. Data are usually not available on the amounts that would be discharged to the workplace or environment. This stems from the fact that the problems and products themselves have not been adequately defined, treatment/control technology has not been specified, and compositions and biological and toxic effects for given product and waste compositions have not been established.

As laboratory analysis of product and waste streams for quantitative measurement of toxic and hazardous chemicals becomes available, Hittman Associates will attempt to estimate the environmental effects to be expected from quantified discharges.

2. IDENTIFY SAMPLING AND ANALYTICAL TECHNIQUES

The Process Measurements Branch of IERL-RTP has developed a three-phased approach to performing an environmental source assessment. In this phased approach, three distinctly different sampling and analytical procedures are envisioned. The Level I Procedure Manual outlines this phased approach, and describes Level I sampling and analytical techniques. A suggested sampling plan for the SRC Pilot Plant at Ft. Lewis, Washington is being prepared and is based upon these techniques. The SRC combustion test at Plant Mitchell, Georgia, utilized a modified Level I Technique. Both of these programs will be discussed in Section 3.

a. The Phased Approach

The phased approach requires three separate levels of sampling and analytical effort. The first level (Level I) utilizes quantitative sampling and analysis procedures accurate within a factor of 2 to 3 and provides preliminary environmental assessment data; identifies problem areas; and formulates the data needed for the prioritization of streams within a process, components within a stream, and classes of materials for further consideration in the overall assessment. The second (Level 2) sampling and analysis effort, after having been focused by Level I, is designed to provide additional information that will confirm and expand the information gathered in Level I. This information will be used to define control technology needs. The third phase (Level 3) utilizes Level 2, or better, sampling and analysis procedures as well as continuous monitoring.

The phased approach recognizes that it is impossible to prepare for every conceivable condition in the first sampling or analysis effort. In some cases, unknown conditions and components of streams will result in unreliable information and data gaps that will require a significant percentage of the sampling or analysis effort to be repeated.

There is a possibility that many streams or even the entire installation may not be emitting hazardous substances in quantities of environmental significance. Conversely, certain streams or sites may have such problems that a control technology development program can be initiated in parallel with a Level 2 effort. If either of these situations could be determined by a simplified set of sampling and analysis techniques, considerable savings could result in both time and funds.

The phased approach offers potential benefits in terms of the quality of information that is obtained for a given level of effort and in terms of the costs per unit of information.

(1) Level 1 Sampling and Analysis. The Level 1 sampling and analysis goal is to identify the pollution potential of a source in a quantitative manner with a target accuracy factor of ± 2 to 3. At the initiation of an environmental assessment, little is known about the specific sampling requirements of a source both practically and technically, and hence the emphasis is on survey tests. For this reason, no special procedure is employed in obtaining a statistically representative sample and the chemical, physical, and biological testing has survey and/or quantitative accuracy consistent with the characteristics of the samples.

At this level, the sampling and analysis is designed to show within broad general limits the presence or absence of, the approximate concentrations of, and the emission rate of inorganic elements, selected inorganic anions, and classes of organic compounds. The particulate matter is further analyzed through size distribution as well as microscopic examination in order to determine gross physical characteristics of the collected material. Biotesting is designed to obtain information on the human health effects and biological effects of the sample.

(2) Level 2 Sampling and Analysis. The Level 2 sampling and analysis goal is to provide definitive data required in the environmental assessment of a source. The basic questions and major problem areas to be addressed have been defined in Level 1 to optimize cost and schedule efficiency. Consequently, Level 2 sampling and analysis is characterized by obtaining statistically representative samples, accurate stream flow rates, and identification and quantification of specific organic and and inorganic elements, species, and/or classes. Biotesting in selected areas is expanded.

b. Multimedia Sampling

Multimedia sampling refers to a philosophy that considers all material discharges, to air, water, or land, to have pollution potential. A Level 1 control technology assessment must investigate all discharge points in addition to feed streams and any internal recycle streams required to establish a baseline for evaluation of control effectiveness.

(1) Classification of Streams for Sampling Purposes. The basic multimedia sampling strategy has been organized around the five general types of sampling found in industrial and energy producing processes.

The five sample types are:

- Gas/Vapor - These are samples for light hydrocarbon and inorganic gas analysis. They include samples from input and output process streams, process vents, and ambient air.
- Liquid/Slurry Streams - Liquid streams are defined as those containing less than 5 percent solids. Slurries are defined as those containing greater than 5 percent solids. Non-flowing pastes are considered solids.
- Solids - These include a broad range of material sizes from large lumps to powders and dusts, as well as non-flowing wet pastes.
- Particulate or Aerosol Samples - These are gaseous streams containing particulates or liquid droplets.

- Fugitive Emissions - These are gaseous and/or particulate emissions from the overall plant or various process units.

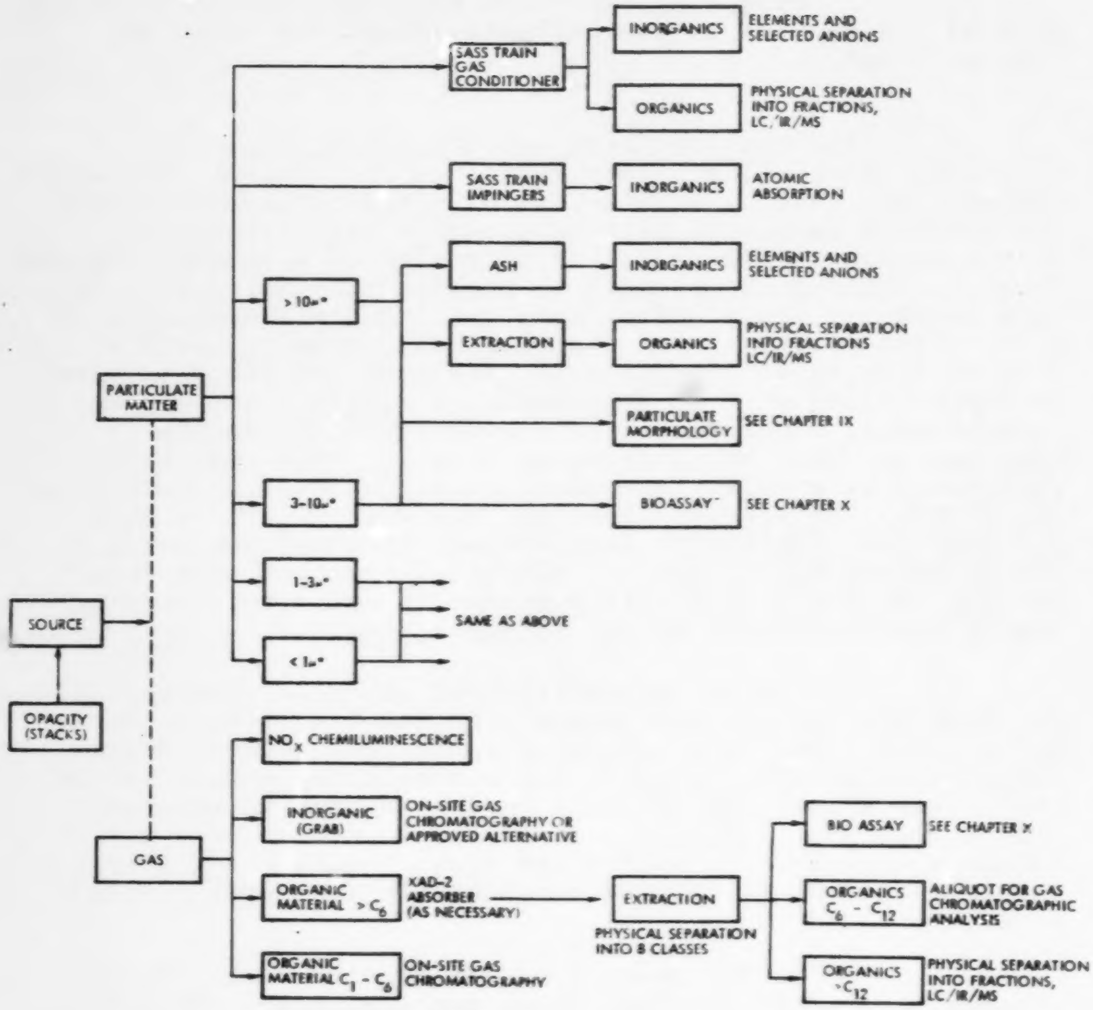
Flow diagrams which show the overall relationship of the samples to the analysis scheme are shown in Figures 2 and 3.

(2) Sampling Point Selection Criteria. The selection of sampling points relies on the concept previously stated: that Level 1 sampling is oriented towards obtaining quantitative data with relaxed accuracy requirements for determination of the pollution potential of a source, whereas Level 2 sampling is intended to acquire more accurately the data necessary for a definitive environmental assessment on prioritized streams. For example, gas stream parameters such as flow rates, temperature, pressure and other physical characteristics will be obtained at a single point under pseudokinetic conditions. This means that the sample is acquired at the point of average velocity which has been determined by a velocity traverse taken at typical points in the stream. At Level 2, however, where quantitative data are required, isokinetic samples must be withdrawn using a full traverse with a port in specific locations away from ducting bends and other obstructions in order to ensure a sample representative of the actual effluent.

Similar considerations apply to site selection for sampling liquids and solids. At Level 1, liquid samples can be taken from tanks or other containers without depth integration and from pipes using a simple tap sample rather than using a multiported probe to take a time integrated sample. In slurry streams, an effort should be made to sample a turbulent or well mixed area, but this and other requirements can be relaxed considerably for Level 1 site selection.

In the case of solids sampling, the standard procedures used in sampling piles and stationary containers are relaxed on Level 1 both by taking fewer increments to make a composite and by relaxing or eliminating the requirements for depth-integrated sampling. For moving solid streams, a simplified sample is obtained by reducing or eliminating the number of increments required for the time-averaging aspect of the sampling procedure.

In most cases, Level 1 sampling methods generally encompass approved standard EPA, ASTM, and API techniques. Modifications are then made to these techniques to adapt them to the time and cost constraints consistent with the Level 1 sampling philosophy. These modifications


INORGANICS
ELEMENTS AND SELECTED ANIONS
SASS TRAIN GAS CONDITIONER
ORGANICS
PHYSICAL SEPARATION INTO FRACTIONS, LC/IR/MS
SASS TRAIN IMPINGERS
INORGANICS
ATOMIC ABSORPTION
ASH
INORGANICS
ELEMENTS AND SELECTED ANIONS
> 10μ*
EXTRACTION
ORGANICS
PHYSICAL SEPARATION INTO FRACTIONS LC/IR/MS
PARTICULATE MATTER
PARTICULATE MORPHOLOGY
SEE CHAPTER IX
3-10μ*
BIOASSAY
SEE CHAPTER X
1-3μ*
SAME AS ABOVE
SOURCE
< 1μ*
OPACITY (STACKS)
NO$_x$ CHEMILUMINESCENCE
INORGANIC (GRAB)
ON-SITE GAS CHROMATOGRAPHY OR APPROVED ALTERNATIVE
BIO ASSAY
SEE CHAPTER X
GAS
ORGANIC MATERIAL > C$_6$
XAD-2 ABSORBER (AS NECESSARY)
EXTRACTION
ORGANICS C$_6$ - C$_{12}$
ALIQUOT FOR GAS CHROMATOGRAPHIC ANALYSIS
PHYSICAL SEPARATION INTO 8 CLASSES
ORGANIC MATERIAL C$_1$ - C$_6$
ON-SITE GAS CHROMATOGRAPHY
ORGANICS >C$_{12}$
PHYSICAL SEPARATION INTO FRACTIONS, LC/IR/MS

*WEIGH INDIVIDUAL CATCHES

Figure 2. Basic Level 1 Sampling and Analytical Scheme for Particulates and Gases

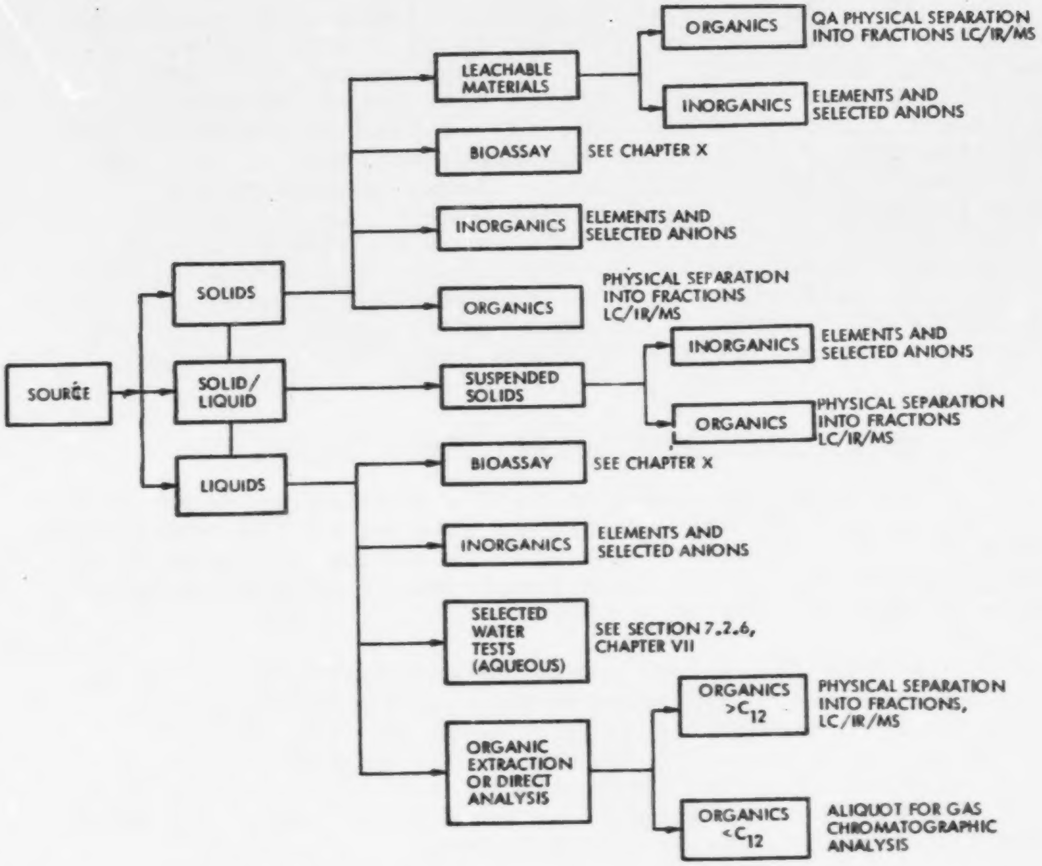

SOURCE
SOLIDS
SOLID/ LIQUID
LIQUIDS
LEACHABLE MATERIALS
ORGANICS
QA PHYSICAL SEPARATION INTO FRACTIONS LC/IR/MS
INORGANICS
ELEMENTS AND SELECTED ANIONS
BIOASSAY
SEE CHAPTER X
INORGANICS
ELEMENTS AND SELECTED ANIONS
ORGANICS
PHYSICAL SEPARATION INTO FRACTIONS LC/IR/MS
SUSPENDED SOLIDS
INORGANICS
ELEMENTS AND SELECTED ANIONS
ORGANICS
PHYSICAL SEPARATION INTO FRACTIONS LC/IR/MS
BIOASSAY
SEE CHAPTER X
INORGANICS
ELEMENTS AND SELECTED ANIONS
SELECTED WATER TESTS (AQUEOUS)
SEE SECTION 7.2.6, CHAPTER VII
ORGANIC EXTRACTION OR DIRECT ANALYSIS
ORGANICS >C12
PHYSICAL SEPARATION INTO FRACTIONS, LC/IR/MS
ORGANICS <C12
ALIQUOT FOR GAS CHROMATOGRAPHIC ANALYSIS

Figure 3. Basic Level 1 Sampling and Analytical Scheme for Solids, Slurries and Liquids

include: 1) reducing point selection criteria; 2) eliminating the requirements for traversing, continuous isokinetic sampling, and replicate sampling in the collection of particulate matter; and 3) use of grab samples for gaseous, water, and solid samples.

(3) Stream Prioritization. Industrial processes are highly complex systems consisting of a wide variety of interrelated components. Level 1 sampling may show that many influent and effluent streams have no environmentally significant impact. These data can be used to substantially reduce the number of samples required for Level 2, and can permit reallocation of resources. Thus, comprehensive stream prioritization based on the Level 1 sampling and analysis effort will identify streams with widely varying environmental priorities. In many cases, the Level 1 information will be sufficient to eliminate certain streams entirely from the Level 2 effort. In other cases, limited resources may require the omission of certain low priority streams.

c. Data Requirements and Pre-Test Planning

The final decision to test a particular plant will be the result of the prioritization studies of the preliminary selection process based on the site selection criteria of a given program, and on the data requirements of the overall program or general EPA objective.

Before the actual sampling and analysis effort is initiated, the data requirements must be established and used to help identify test requirements as well as any anticipated problems. The following paragraphs present a general summary of these requirements and the planning function which must be applied or expanded to meet the needs of the individual tests to be performed.

(1) Process Data Needs

Before travelling to a plant for a pre-test site survey, it is necessary to become familiar with the process used at the site. This involves understanding the chemistry and operational characteristics of the various unit operations as well as any pollution control processes. It is particularly important to know that detailed relevant process data are necessary for the sampling and analysis effort as well as for the overall environmental assessment. The reasons for this are:

- From a knowledge of the process and the composition of input materials and products, conclusions about pollutants likely to be found in waste streams can be drawn.

- One must know where to look for waste streams, including fugitive emissions.
- One must know how plant operating conditions are likely to affect waste stream flow rates and compositions.
- Thorough familiarity with the process permits design of a proper sampling program.
- Thorough knowledge of the interrelationships among process variables permits extrapolation to conditions in other sizes of the system being assessed, and
- Detailed process data are the basis from which control technology development programs proceed, should environmental assessments indicate such need.

Familiarization with the process is also necessary so that a checklist of the requisite data can be developed, including temperatures, pressures, flow rates, and variations of conditions with time for the pre-test site survey.

(2) Pre-Test Site Survey

After establishing the necessary process data needs and making a tentative selection of sampling points, a pre-test site survey should be performed. At the site, the survey team should meet with the plant engineer to verify the accuracy of the existing information and arrange for the addition of any missing data. Using this information, the survey team will then proceed to select the actual sampling sites with the following criteria in mind:

- The sampling points should provide an adquate base of data for characterizing the environmental impact of the source on the environment within a factor of 2 to 3.
- When possible, each sampling point should provide a representative sample of the effluent streams. (This is a desirable but not a strict requirement of Level 1 sampling.)

- The sampling site must have a reasonably favorable working environment. The survey personnel must consider the temperature and noise level in the sampling areas, if protection from rain or strong winds exists, and whether safe scaffolding, ladders, pullyes, etc., are present.

The identification of support facilities and services is an essential aspect of the site survey. If electrical power and water are not available for hook-up to a mobile test van, it must become self sufficient and these services designed into the van.

The results of the pre-test survey must be sufficiently detailed so that the field test problem of sampling the correct process stream at the proper sampling location, using the appropriate methodology will be completely defined prior to approval of the field test and team at the source site.

(3) Pre-Test Site Preparation

It is assumed that any site or sample point preparation will be completed before arrival of the sampling team. This would include: erection of scaffolding, availability of electrical power, fitting of sample ports and nozzles at the required locations, etc. The sampling team is responsible for final mating of the sample device to the port, and should be equipped with miscellaneous valves, fittings, other devices, and tools for adaptation.

d. Sampling Equipment and Methodology

For the purpose of Level 1 assessment of gas/vapor streams, a single grab sample is sufficient although planning is necessary to ensure that sample acquisition is made at a reasonably representative plant in the stream or process cycle. The grab sample may be taken in one of these ways, depending on the pressure of the steam in question. The three grab samples types are high pressure line, grab purge, and evacerated grab samples and are illustrated in Figures 4, 5, and 6.

To collect gaseous steams containing particulates, a source assessment sampling system (SASS) train is recommended for Level 1.

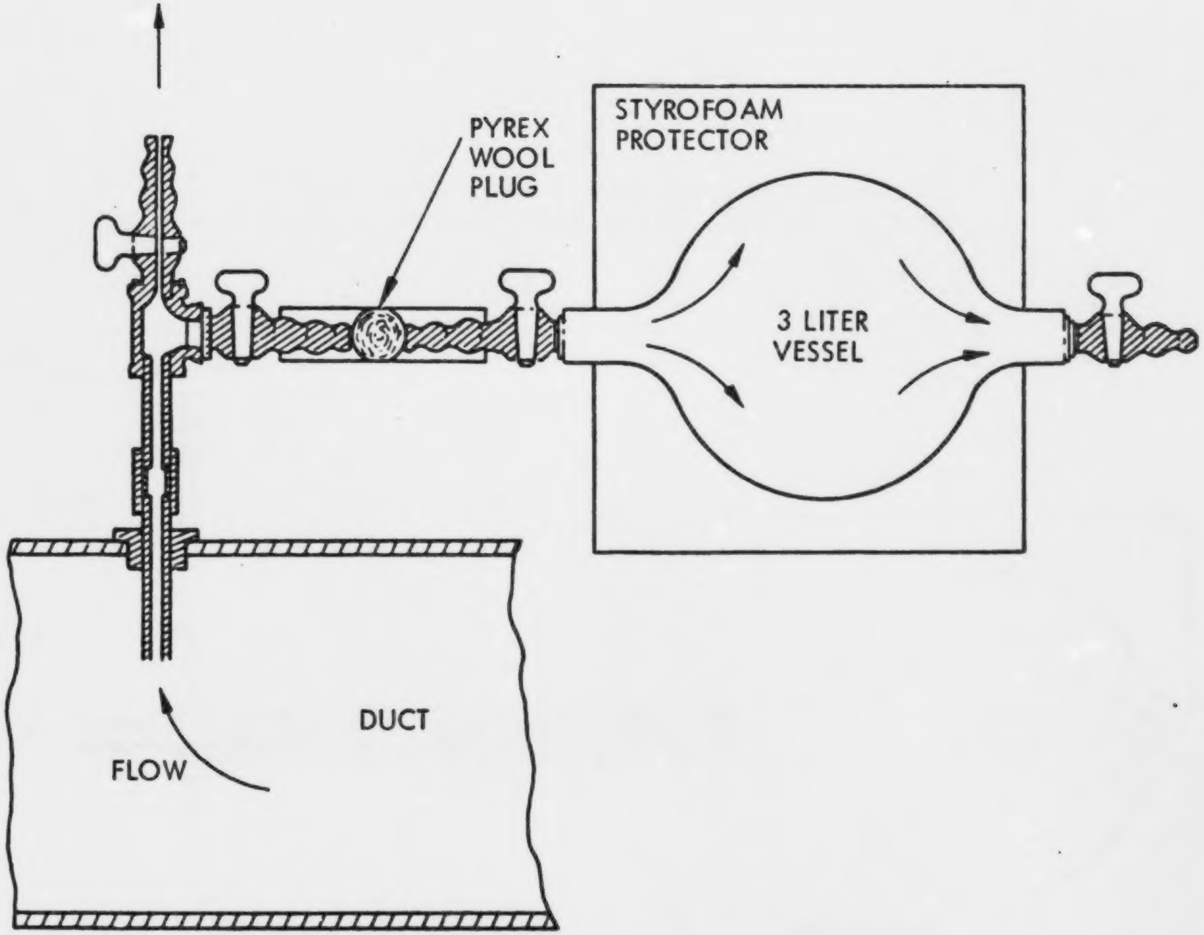


Figure 4. High Pressure Line Grab Purge Sampling Apparatus

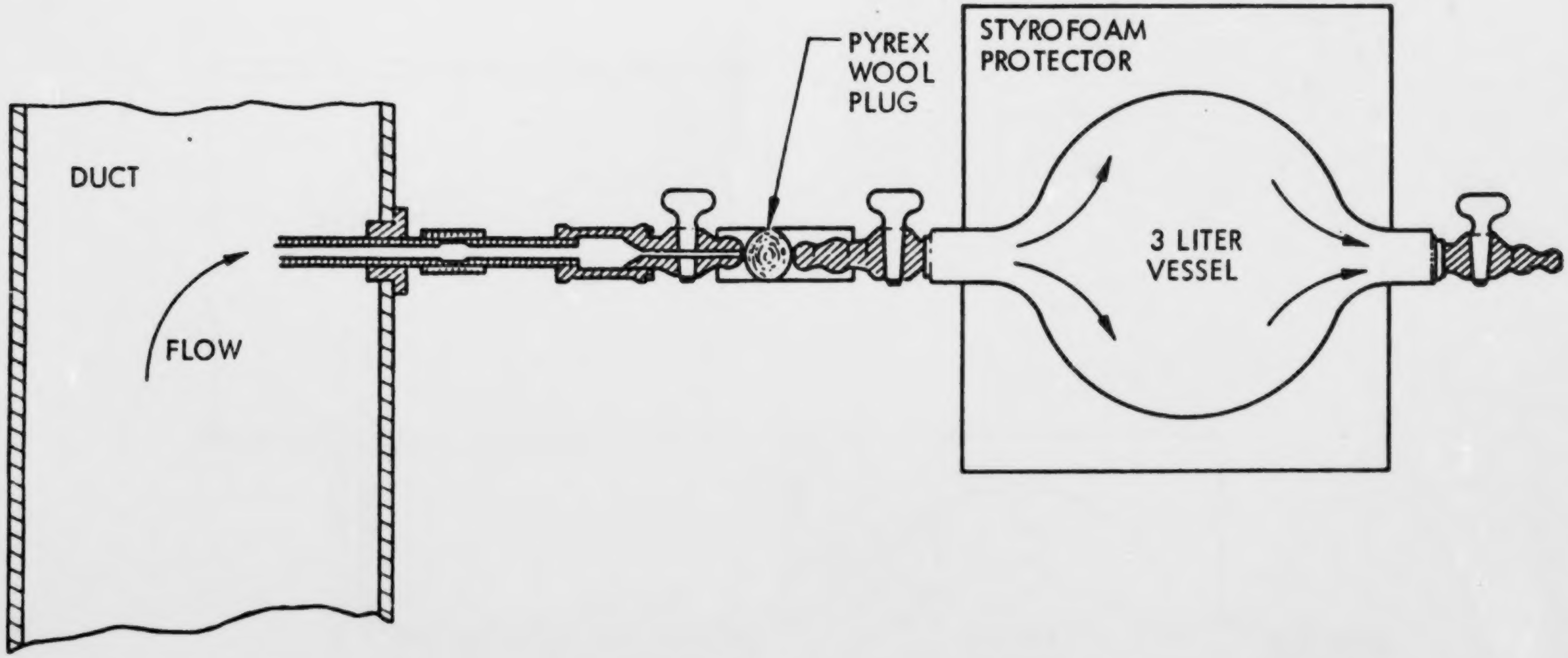


Figure 5. Low Pressure Grab Purge Sampling Apparatus (for Less than 2 Atmospheres Pressure)

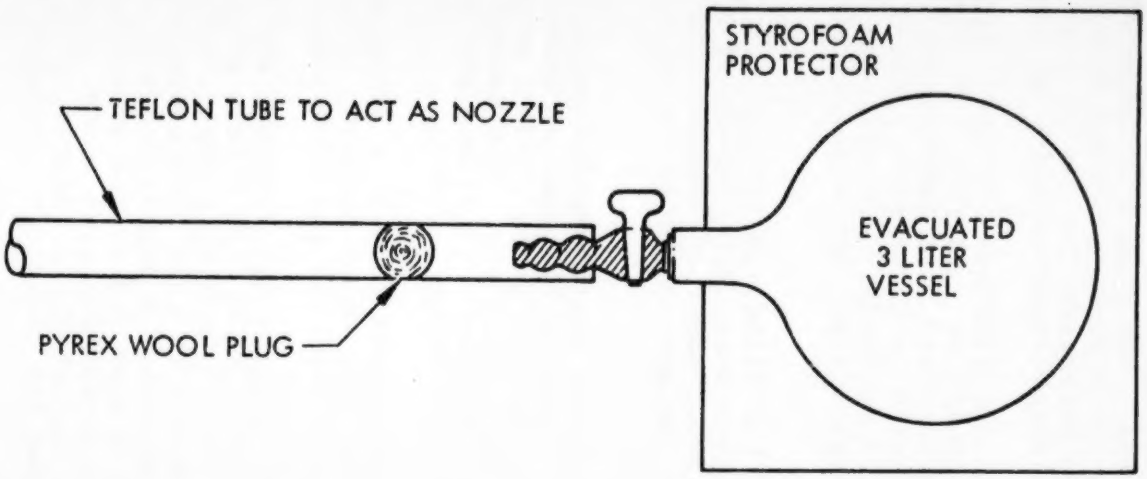


Figure 6. Evacuated Grab Sampling Apparatus (for Subatmospheric Pressures)

A diagram of the SASS train appears in Figure 7. This sampling device includes cyclones and a filter to collect particulates, a sorbent trap to collect C_7 - C_{12} hydrocarbons, impingers, and associated temperature controls, pumps, and meters. The sample is obtained from the flue gas duct by means of a probe inserted through the duct work and positioned to intersect the gas flow at a point having flow characreristics representative of the bulk flow.

Particulates are removed from the sample first, passing it through a series of cyclones. For the SRC tests, these cyclones were maintained at a temperature of 400°F. Particulates are collected in three size ranges, $>10\mu$, 3 to 10μ, and 1 to 3μ, respectively. The cyclones are followed by a standard fiberglass filter, which collects a fourth size range, $<1\mu$.

Gas leaving the filter is cooled to approximately 68°F and passed through a cartridge containing XAD-2 resin. This resin absorbs a broad range of organic compounds. Condensate produced when the gas is cooled is collected in a condensate trap.

A series of three impingers followes the resin cartridge. The first contains hydrogen peroxide solution, which removes reducing components to prevent deterioration of the following impinger solutions. The second and third impingers, containing ammonium thiosulfate and silver nitrate, collect volatile inorganic trace elements.

Next, the gas passes through a dehydrating agent, in order to protect the pump which follows. Finally, the gas flow rate is metered, and the gas is vented.

During Level 1 sampling, fugitive air emissions are usually sampled utilizing a high volume sampler with an XAD-2 absorbent trap for collecting gaseous hydrocarbons. See Figure 8. This method is used when a specific source such as a coal pile generates a highly diffuse cloud over an extensive area. When a specific source generates an emission that might be broadly classified as a plume, a SASS train is used. In the case of waterborne emissions, plug collectors (see Figure 9) are used for collecting surface runoff.

Liquid and slurry samples are collected by heat exchange, trap sampling, or dipper sampling. Figure 10 shows the heat exchanger system recommended for high temperature lines. Solids are collected by either shovel grab samples or boring techniques. Level 1 a single grab samples is taken. During Level 2 a composite is made of a series of grab samples gathered.

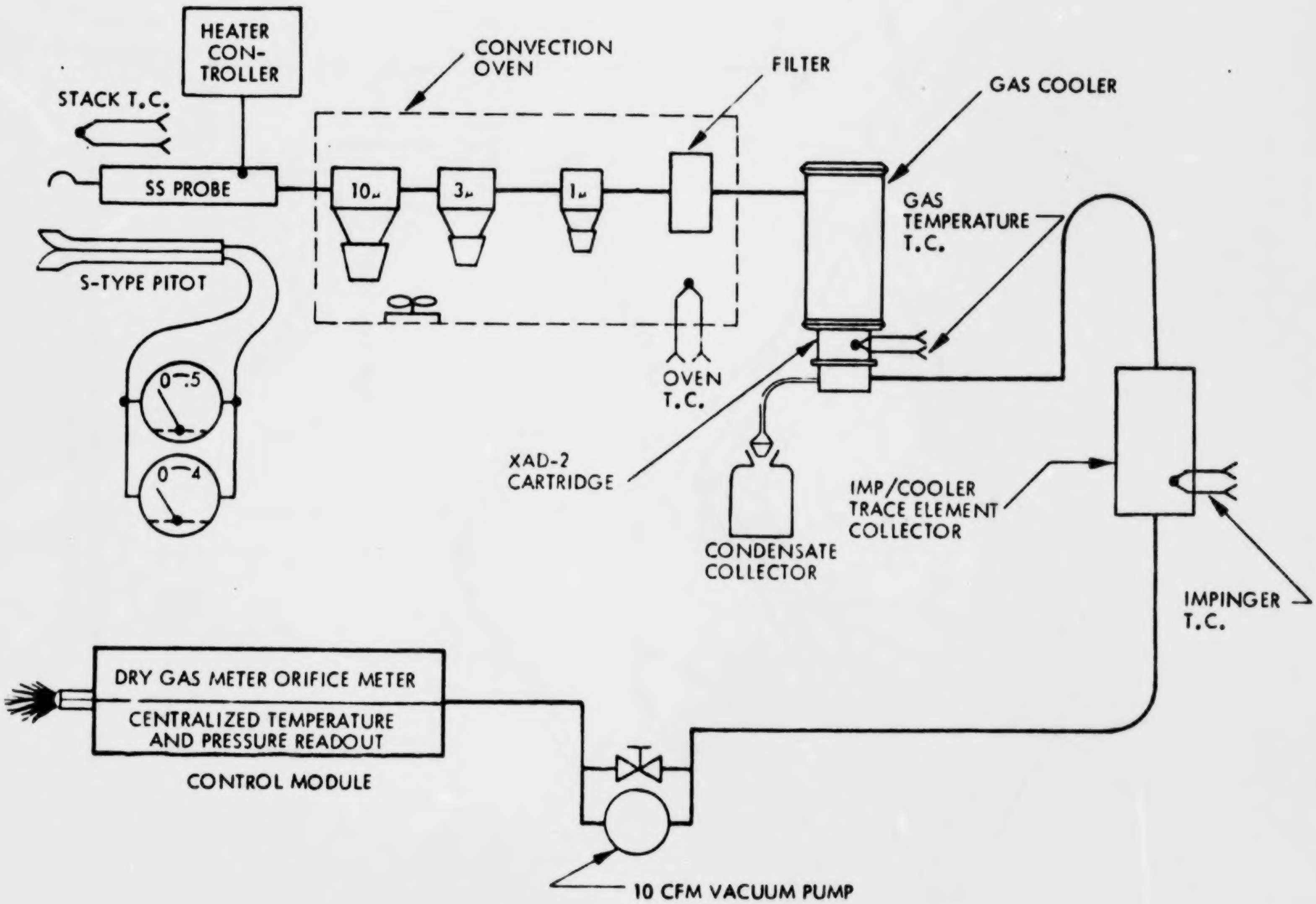


Figure 7. Source Assessment Sampling Schematic

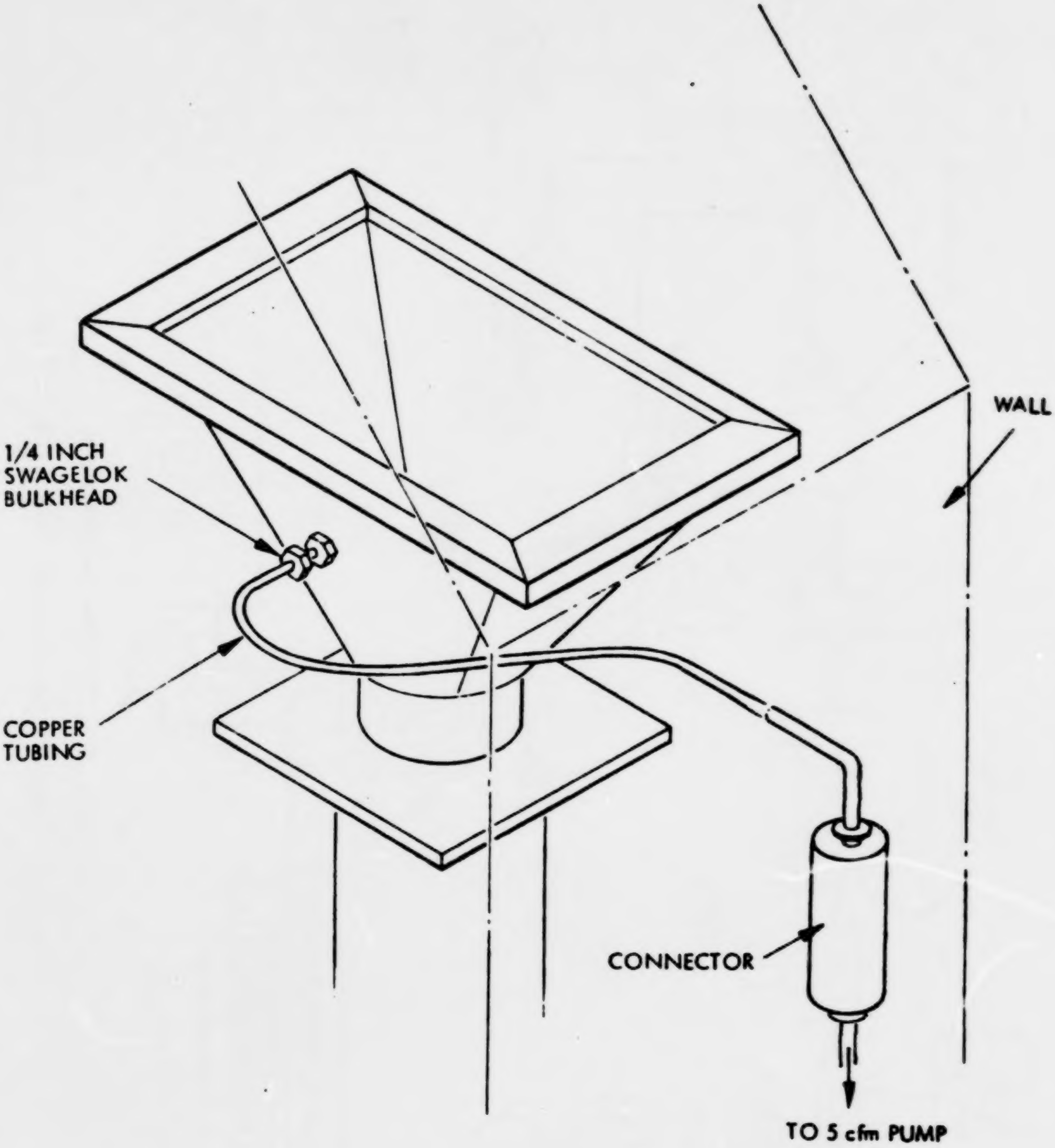


Figure 8. Expanded View of Connections of XAD-2 Cartridge to High Volume Sampler

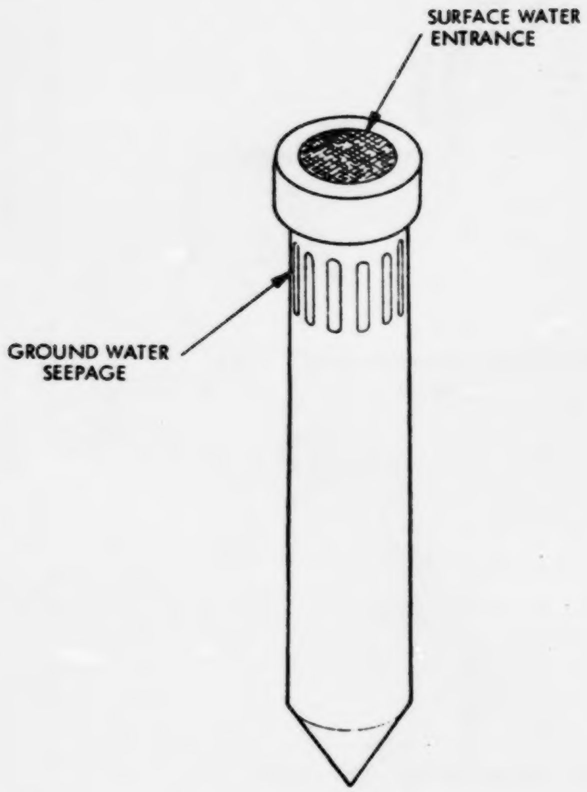
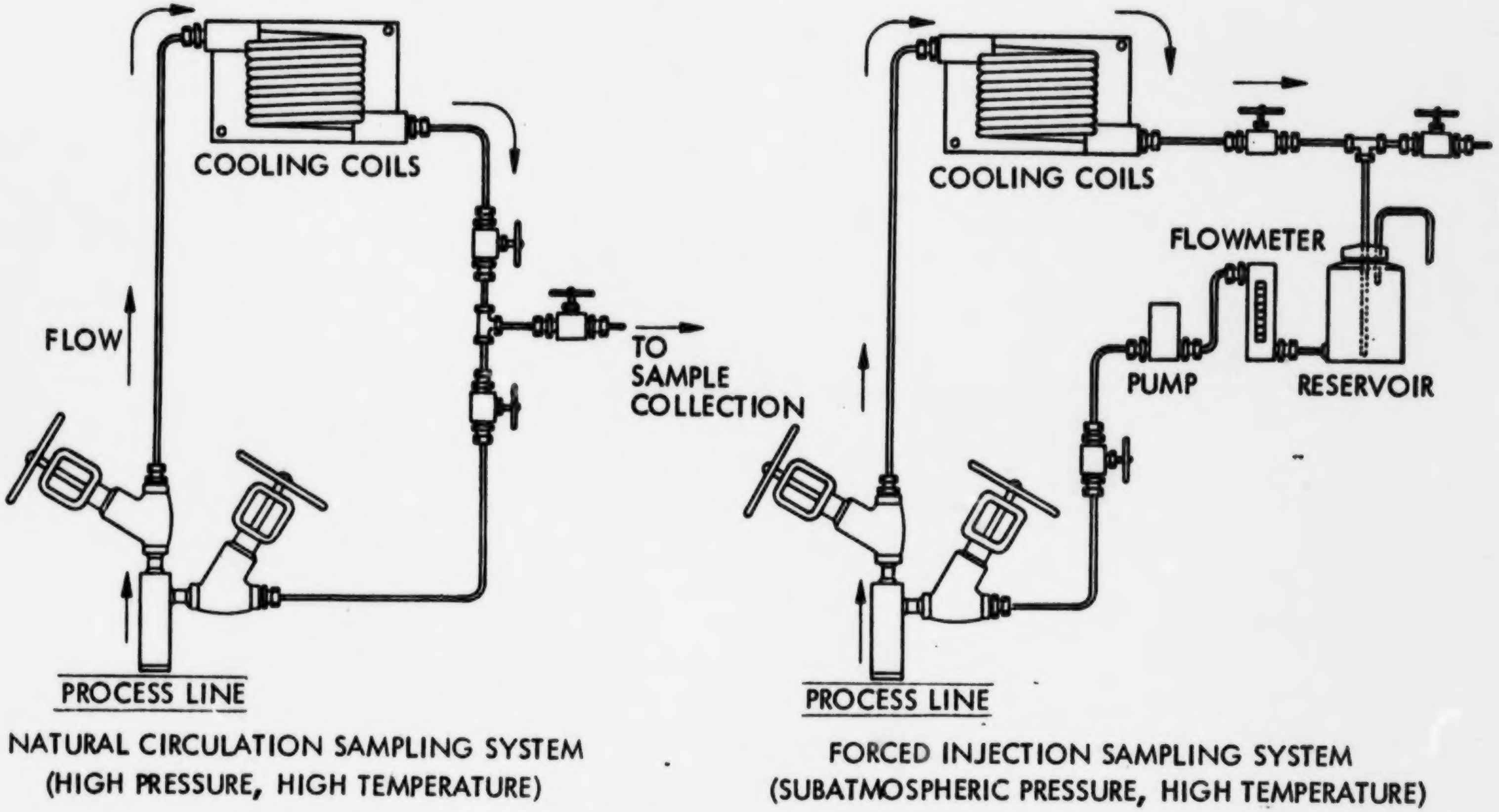


Figure 9. Plug Collector for Fugitive Water Samples



NATURAL CIRCULATION SAMPLING SYSTEM
(HIGH PRESSURE, HIGH TEMPERATURE)

FORCED INJECTION SAMPLING SYSTEM
(SUBATMOSPHERIC PRESSURE, HIGH TEMPERATURE)

Figure 10. Sampling Apparatus for HPHT (High Pressure High Temperature) Lines

3. TEST PROGRAM DEVELOPMENT

a. Introduction

During the past year work was performed on two major test programs. A suggested sampling plan for the Ft. Lewis, Washington Solvent Refined Coal Pilot Plant, operated by Pittsburgh and Midway, is nearing completion. The purpose of this task is to provide guidance in a multimedia sampling program. Much of the information was exerpted from the IERL-RTP Procedure Manual: Level 1 Environmental Assessment (EPA-600/2-76-160a). The phased approach and sampling methodologies were the basis for the document.

A test plan was also developed for a combustion test at Georgia Power Company's Plant Mitchell where Solvent Refined Coal was burned for the first time in a commercial utility boiler. The test occurred, and samples were collected. A paper on the subject was delivered at the EPA Symposium on Environmental Aspects of Fuel Conversion Technology, III in Hollywood, Florida. The major portion of the analysis is currently being performed and a final report of the test will be prepared when these results are available.

b. Test Plan for The SRC Pilot Plant

The coal liquefaction plant at Ft. Lewis, originally designed to operate via the SRC process, has been modified to the "SRC-II" configuration. The SRC process removed essentially all of the ash and pyritic sulfur and more than half of the organic sulfur contained in the coal feed. It made a solid product that could be pulverized and burned in the same manner as the coal. The SRC-II process recycles a portion of the product slurry as solvent which increases the conversion of coal to lower molecular weight fuels thus making a liquid rather than a solid product. It is less complex than the original process and eliminates the difficult filtration step to remove ash from the coal.

All process and waste streams including fugitive emissions were identified in the plant. A comprehensive test plan was outlined for all of these solid, liquid and gaseous streams. However due to time and economic constraints, a limited number of streams can be sampled under this program. In order to select streams for the sampling, the various process and waste streams were categorized as follows:

- Category I: This category includes all air, water, and solid waste streams that directly impact the environment. Included in this category are vents, fugitive emissions, effluents from the wastewater treatment plant and solids to be disposed of in landfills. Also included in this category are the streams feeding the flare, product streams, and raw water.

- Category II: In this category are all waste streams prior to treatment or combination with other streams, and subsequent discharge into the environment. "Treatment" includes incineration, particulate removal, wastewater treatment and other control technologies.
- Category III: All identified process streams, except product streams, fall into this category.

Only Category I streams will be sampled under Phase I of this test program. Should additional testing occur, some Category II streams may be sampled, in addition to more intensive testing of some of the Category I streams. At this time it is anticipated that no Category III streams will be included by EPA during this sampling program. It would be valuable if these streams could be tested by ERDA in the course of the pilot plant program and preferably at the same time as the environmental sampling.

Level 1 testing will provide a basis for selecting which streams should be sampled again, the type of sampling program, and what specific analyses should be performed. Streams with high concentrations of hydrocarbon, particulates, toxic compounds, trace metals, BOD's etc. will be identified. Some streams may be eliminated from further study. The Phase II program will be used to prepare an environmental assessment of the Ft. Lewis Facility.

Samples and subsequent analyses performed during Phase II will be directed toward those streams selected for more study, measuring actual discharge rates and levels of specific components found in Phase I. These samples will consist of continuously withdrawn sample streams, weight or volume proportioned composites, or other representative portions of the streams under study. Where continuous monitoring is feasible this may prove to be a preferred technique.

During the sample period, stream data must be obtained as well. Flow rates, including the variation in flow rate must be known to prepare representative composites. This is necessary to determine the total discharge quantity of the constitutents under study. Where the stream flow varies, continuous recording of the instantaneous flow may be necessary.

In addition to flow rates, stream conditions and properties must be determined. Temperature and pressure obviously must be known. It will be necessary to know the density, also if volumetric flows are recorded. Ultimately, the properties which will be of interest will be determined by the specific streams under study.

In Phase II streams that have not been sampled during Phase I may be sampled. This situation could arise if, for example, a control module having multiple feed streams (which were not sampled in Phase I) shows an unexpected component in its discharge. In such as case it may be necessary in Phase II to sample all of the streams feeding the module to determine the component source.

Sampling during Phase II should extend over a representative time span. The minimum period would be on the order of one shift. In some cases it may be as long as several days to a week, and run throughout all three shifts. This will ensure the plant operating variations are included in the sample period.

Phase II analysis will be quantitative instead of qualitative. It will focus on a few components of interest. Results of the Phase II effort will define quantities of specific materials being discharged and point out areas needing additional control technology development.

Identification and quantification of constituents suspected of being present will be performed. Specific polynuclear aromatic hydrocarbons, trace metals, and inorganic compounds such as cyanides are likely pollutants to be tested for.

With the sampling and analysis results, an assessment of effluents from the Fort Lewis SRC pilot pant can be prepared. This information would prove invaluable in anticipating pollutant levels at a full size commercial SRC facility. Planning and design of the commercial facilities can be partially based upon these results.

c. SRC Combustion Test

On June 14th, 1977 Solvent Refined Coal was burned in a commercial utility boiler for the first time, for the purpose of determining whether SRC could replace coal as a primary fuel in a pulverized coal-fired boiler. In addition, to boiler efficiency tests, flue gas samples were collected and analyzed.

Both ERDA and its contractors, and EPA and its contractors including Hittman Associates, Inc., were involved in this combustion test. Preliminary results have been obtained and Hittman Associates, Inc., has prepared a paper discussing these data. The test was conducted in three phases.

In Phase I of this program, low sulfur Kentucky coal was burned in the existing, unmodified 22-1/2 Mw pulverized coal boiler. Following replacement of the original burners with dual register burners and accompanying modifications, Phase II of the test was conducted. In this phase, as in Phase I, the boiler was fired with low sulfur Kentucky coal. In Phase III, following adjustment of the burners and the pulverizers, SRC was burned. In each of the three phases of the program, the boiler was operated at full (approximately 21 MW), medium (approximately 14 MW), and low (approximately 7 MW) load conditions.

Precipitator efficiency tests were run, ash resistivity was determined, and air emission levels were evaluated using EPA-5 and ASME trains. In addition to particulates, a number of gases, including CO_2, CO, N_2, O_2, and SO_2 were monitored.

In addition, during Phases II and III, flue gas sampling was conducted using a SASS train to collect samples for laboratory analysis, using a modified EPA Level I procedure. Grab samples were obtained for on-site analysis for C_1 - C_6 hydrocarbons, SO_x, N_2, CO, and O_2.

Results of the SASS train analyses are not presently completed. No bioassays will be performed. However, in addition to the remainder of the standard Level 1 analyses, all samples collected that contain organics will be analyzed for a selected group of polynuclear aromatic hydrocarbons.

Analytical results of the grab samples and continuous monitor indicate that:

- There were no detectable levels of C_1 - C_6 hydrocarbons.
- SO_x and NO_x levels were roughly equivalent with those from low sulfur coal combustion.
- SO_x and NO_x concentrations were highest at full load and lowest at low load.

Observations made during the test include:

- Particulates collected by the SASS train during combustion were approximately seventy percent carbon as compared with a typical coal fly ash of less than ten percent.
- Particle size of SRC ash was much smaller than that of coal fly ash.
- Precipitator efficiency was drastically reduced probably due to the high resistivity of the high carbon ash

Once results of SASS train sample analyses are available, a detailed report will be prepared interpreting these results.

4. INPUT-OUTPUT MATERIALS CHARACTERIZATION

Available input-output materials characterization for coal liquefaction processes is usually incomplete or not in a form suitable for environmental assessments. Since commercial coal liquefaction facilities do not exist, most studies, whether for economic analysis, engineering projection, process assessment, or environmental consideration, have had to use conceptualized models for solid waste and residue use/disposal, treatment/control technology, auxiliary facilities, liquid/ solid separation, and other modules necessary for full-scale operation. Basing input-output materials characterization on conceptualized models gives only estimates of the environmental discharges, but it is the only method currently available.

Input-output materials characterization for coal liquefaction processes may be put in a form suitable for environmental assessments by use of the following available data:

- Reported material balances
- Use of deposited sample analyses
- Physical-chemical relationships
- Analogies with other processes
- Comparisons with other industries
- Conceptualized modeling of missing process modules.

These data sources are discussed in the following paragraphs.

a. Reported Material Balances

Material balances, either actual or conceptual, have been reported for several coal liquefaction processes. Coal compositions are also available from various reported sources. Partial material balances in the form of efficiencies, or barrels of products per ton of coal, have also been published. Putting all of this published information together provides a framework for overall environmental characterization of the processes.

b. Use of Reported Sample Analysis

Reports of products and/or waste stream analyses go all the way back to the German Bergius process of World War II. Although these data are incomplete, they can be used to provide a more detailed description of the environmental discharges than can be obtained from material balance information. Invariably the analysis has shown that coal liquefaction product and residue waste streams contain large quantifies of aromatics, particularly polynuclear aromatic hydrocarbons. Wastewater streams contain phenolics, organics, and inorganics.

Ash samples contain metals and inerts. Residues contain ash, char, and high boiling polynuclear aromatic hydrocarbons. The combination of material balance quantities with the reported stream compositions starts to define environmental discharges.

c. Physical-Chemical Relationships

In the absence of any detailed information on material balance and sample analysis data, physical-chemical relationships may be used to predict the discharge pattern of coal liquefaction products and wastes. Coal liquefaction introduces a known composition and amount of coal and hydrogen into the liquefaction process. Inerts such as nonvolatile metals, rock and dirt will pass through the system and emerge unchanged. Some of the coal and hydrogen will be transformed into new organic products and wastes in the hydrogenation module. All subsequent process operations separate the effluent from the hydrogenation into desirable fractions, usually through physical-chemical particle size, flammability, thermal stability and other physical-chemical relationships. Using a knowledge of these properties, the environmental discharges from the coal liquefaction process can be further refined.

d. Analogies With Other Processes

Input-output characterization data from coal liquefaction processes is often available in pieces. For a given process, the amount and composition of one environmental effluent may be available, but not the others. For another process, the amount and composition may be available for one or more of the other streams. By combining information on analogous streams, effluent amounts and compositions may be estimated for the overall processes. This method also provides cross-checks on the similarity or differences of products and wastes from the different processes.

e. Comparisons with Other Industries

Input-output materials characterizations can be drawn from industries with similar products and wastes. The most similar industry to coal liquefaction is the coal tar industry. Prior to the advent of readily available and low cost petrochemicals, the coal tar industry supplied most of the inorganic chemicals for industrial purposes. Aromatic and polynuclear compounds comprise: a large portion of coal tar, which when fractionated yields products ranging from benzene and phenols to tars and asphalts. It is expected that many of the workplace and environmental problems with coal liquefaction will be similar to those for coal tar operations.

The petroleum industry is a second industry which has analogies with coal liquefaction processes. Fractionation and recovery of products by physical-chemical technology, treatment/control of atmospheric, waterborne and residue wastes has received extensive attention in this industry and some of the developed technology is applicable.

Coal-fired utility boilers and coal gasification operations have waste residues and ashes similar to coal liquefaction. Metal and inert composition data on these residues can be useful in defining the environmental discharges expected from coal liquefaction and the solubility, leachability and other characteristics of these wastes.

f. Conceptualized Modeling of Missing Process Modules

In the absence of defined process modules, it is necessary to model the missing portions. Eventually, the coal liquefaction processes may be expected to develop their own fine structure, with all the complexity of a modern-day petroleum refinery. The scale-up from bench scale, to PDU status, to pilot plant size shows a marked proliferation in process equipment and function. A similar increase in equipment complexity and specialized function may be expected for commercial units. Similarly, development of processes and commercialization may be expected to increase the efficiency of conversion from coal to products and reduce the environmental discharges.

Three points can be made for this projected pattern:

- Conceptualized modeling of missing process modules should given conservative environmental discharge values.
- Until specific commercial processes are available, conceptualized modeling using general modules can be used to define environmental discharges with satisifactory accuracy.
- To date environmental discharges have been related to specific processes. In the future, the definition of environmental discharges will depend more on the product(s) desired and the process variables needed to obtain them than on the process itself.

Tables 2, 3, 4, and 5 give preliminary input-output materials characterizations for four conceptualized 50,000 bbl/day commercial coal liquefaction facilities. At this point in the input characterization development, the similiarities should be stressed rather than the differences. For example, the bottoms fraction from this EDS process consists of 4,866 tons per day, while the Synthoil process has only 3,536 tons per day of char after pyrolysis through a multiple hearth furnace (conceputalized by Synthoil developers). Pyrolysis or other treatment of EDS bottoms could reduce the amount of bottoms to a lower figure comparable to the Synthoil char. Similar treatment could reduce the 5482 tons per day of solid wastes from the H-Coal process. The similarity is that all four processes have 3500 to 5500 tons per day of solid and residue waste for use/treatment/disposal. This quality of solid and residue waste represents a significant area of environmental discharge which needs to be given priority attention. Similar attention needs to be given to treatment/control technology for process wastewater and air emissions.

TABLE 2. INPUT-OUTPUT MATERIALS FOR 50,000 BBL/DAY SYNTHOIL SYSTEM (TONS/DAY)

In		Out	
1. Prepared coal	16,667	1. Heavy product	7,090
2. Water injection	1,904	2. Light product	1,705
3. Make-up gas (44% H_2)	1,519	3. By-product (liquid)	1,254
4. Make-up water (in the acid gas removal)	61	4. By-product (gas)	729
5. Chemicals (make-up to the amine system)	12	5. Acid gas to sulfur recovery	1,840
TOTAL	20,163	6. Char	3,536
		7. Wastewater (total)	4,009
		TOTAL	20,163

TABLE 3. INPUT-OUTPUT MATERIALS FOR 50,000 BBL/DAY H-COAL SYSTEM (TONS/DAY)

In			Out		
1.	Dry pulverized coal	19,122	1.	Ammonia	115
2.	Make-up gas (45% H_2)	1,582	2.	Sulfur	799
	TOTAL	20,704	3.	Phenol	13.5
			4.	Naptha	1,550
			5.	Product oil	8,000
			6.	Gases	2,600
			7.	Wastes	5,873.5
			8.	Water	1,753
				TOTAL	20,704

TABLE 4. INPUT-OUTPUT MATERIALS FOR 50,000 BBL/DAY EXXON DONOR SOLVENT SYSTEM (TONS/DAY)

	In			Out	
1.	Raw coal	18,181	1.	Hydrogen sulfide	485
2.	Hydrogen	579	2.	Ammonia	227
	TOTAL	18,760	3.	Phenols	20 (est)
			4.	C_1	134
			5.	C_2	84
			6.	C_3	89
			7.	C_4	37
			8.	Light naptha	886
			9.	Heavy naptha	2,866
			10.	Middle Distillate	6,234
			11.	Heavy fuel oil	54
			12.	Bottoms	5,441
			13.	H_2O	2,118
			14.	Hydrogen	85
				TOTAL	18,760

TABLE 5. INPUT-OUTPUT MATERIALS FOR 50,000 BBL/DAY SRC SYSTEM (TONS/DAY)

	In			Out	
1.	ROM coal (5% moisture)	31,520	1.	SNG	3,414
2.	Oxygen	2,745	2.	LPG	964
3.	Water	45,774	3,	Naptha	786
	TOTAL	80,039	4.	Fuel oil	5,061
			5.	SRC	10,649
			6.	Sulfur	517
			7.	Ammonia	70
			8.	Phenol	37
			9.	Residue & Slag	5,090
			10.	Water losses	39,528
			11.	Waste gases	13,923
				TOTAL	80,039

E. TECHNOLOGY TRANSFER (INPUT-OUTPUT)

1. STANDARDS OF PRACTICE MANUAL

The first Standards of Practice Manual for a coal liquefaction process is under preparation by Hittman Associates, Inc., Columbia, Maryland. The SPM is designed to furnish environmental guidelines and best control/disposal options for liquefaction processes currently under development.

The SRC-1 process was chosen for the study. A pilot plant for the process has been operated by ERDA at Fort Lewis, Washington since September 1974. It was felt that a definitive study of the process and its waste streams, and their optimum treatment methodologies would provide a service to the future commercialization of this process.

Progress includes completion of material balances for the process and waste streams. From this basis, written and schematic descriptions of process modules and control/disposal modules were added. Best control/disposal practices have been selected for all wastestreams. Pertinent federal, state and local environmental standards have been assembled relative to a projected plant location. Partially complete are descriptions of environmental emissions and factors achievable and control/disposal costs.

Remaining work includes a detailed description of the basic process, which will outline control options for specific emissions and their respective costs for each module. A large portion of this effort will consist of assembling information from previous sections of the manual and summarizing them into clear, succinct unit operations for each module. Estimated completion date is October 31.

APPENDIX A

Process Flow Diagrams

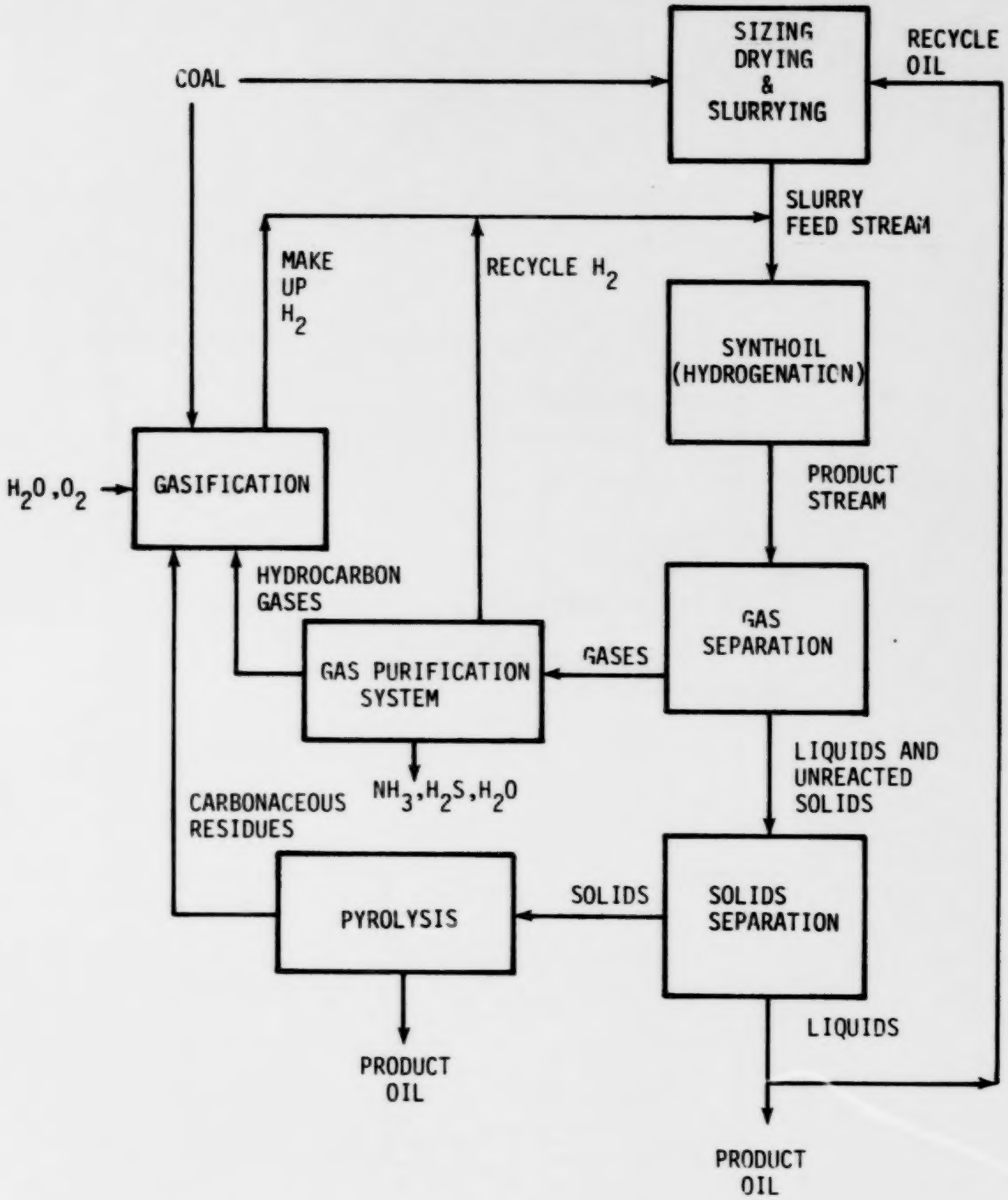


Figure 1. Synthoil System

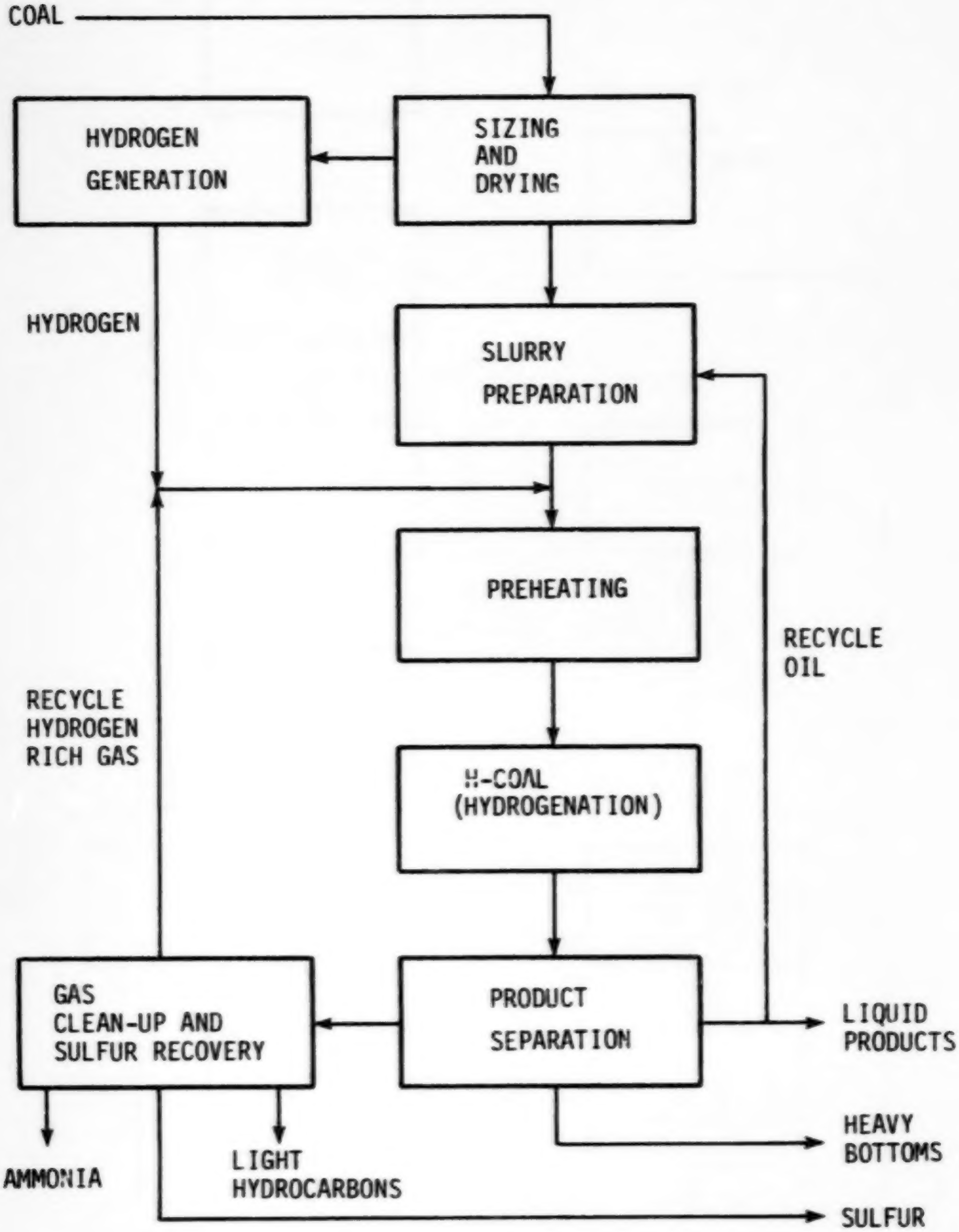


Figure 2. H-Coil System

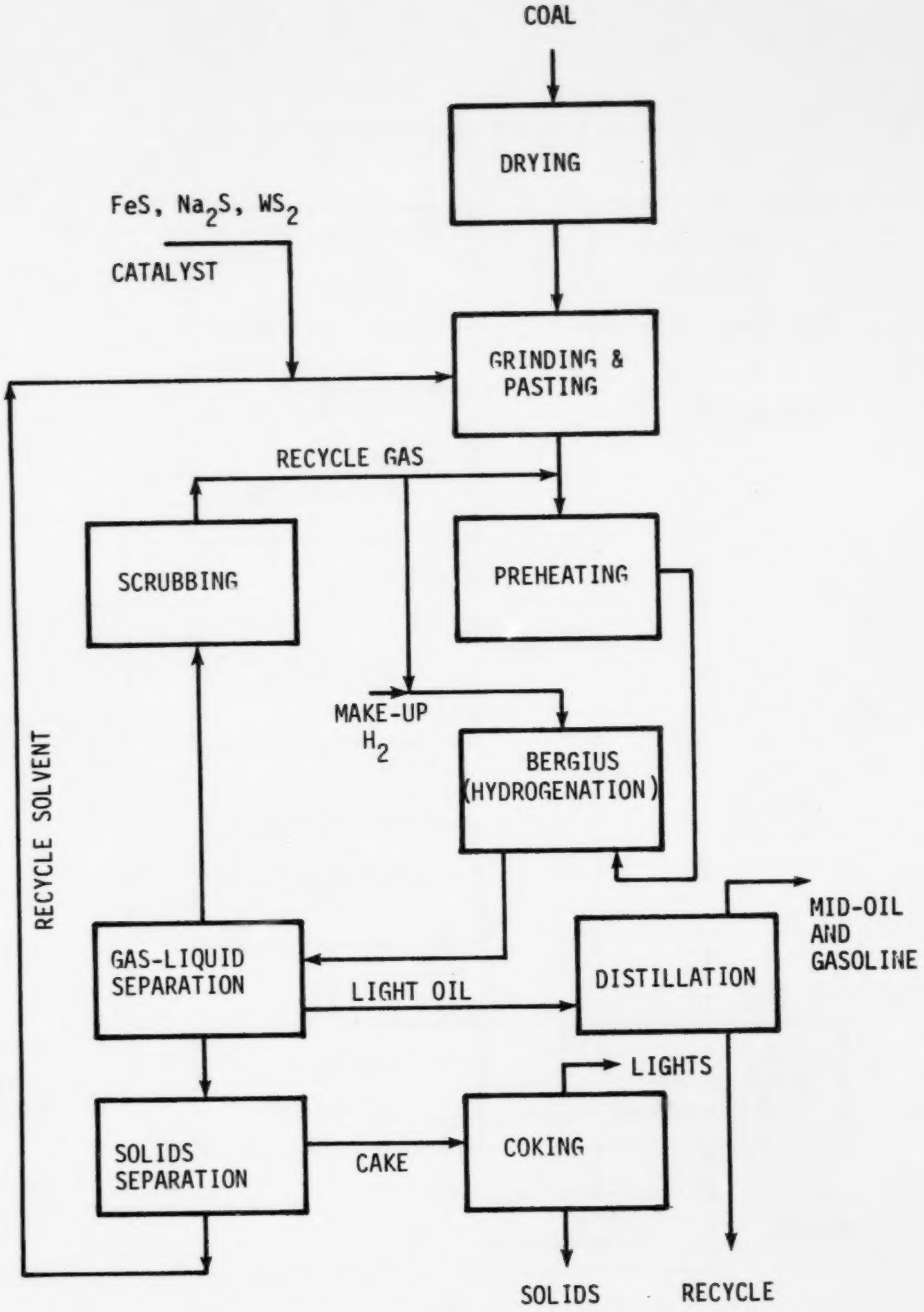


Figure 3. Bergius System

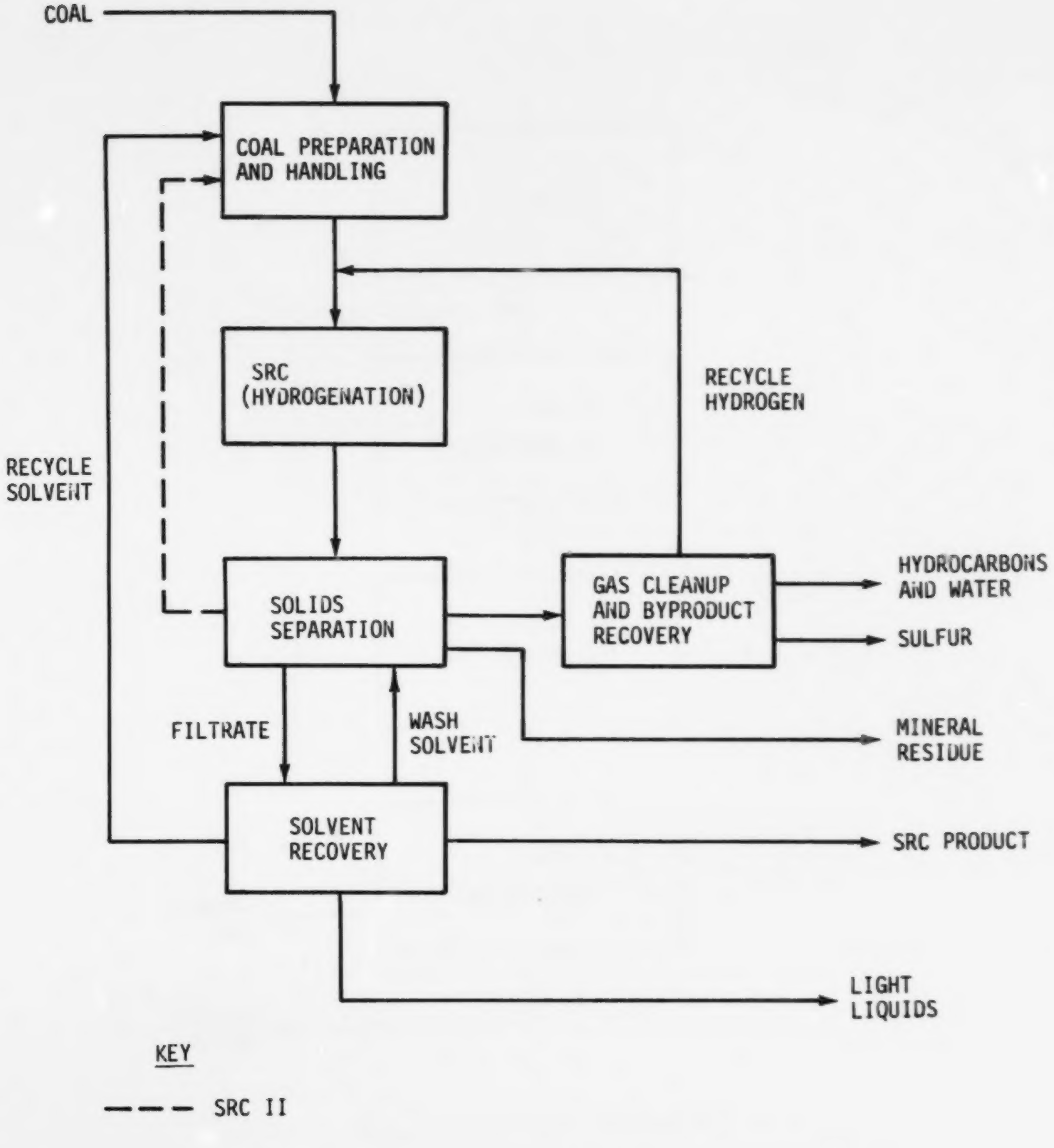


Figure 4. Solvent Refined Coal System

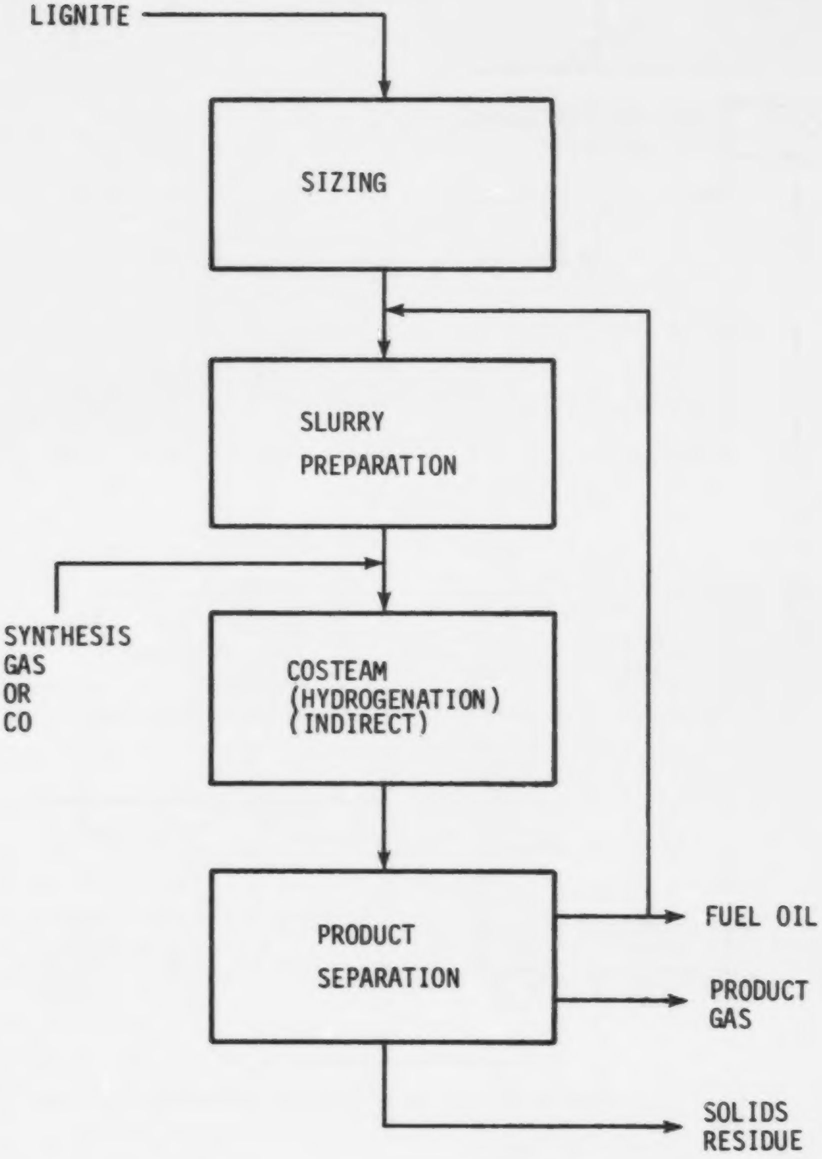


Figure 5. COSTEAM System

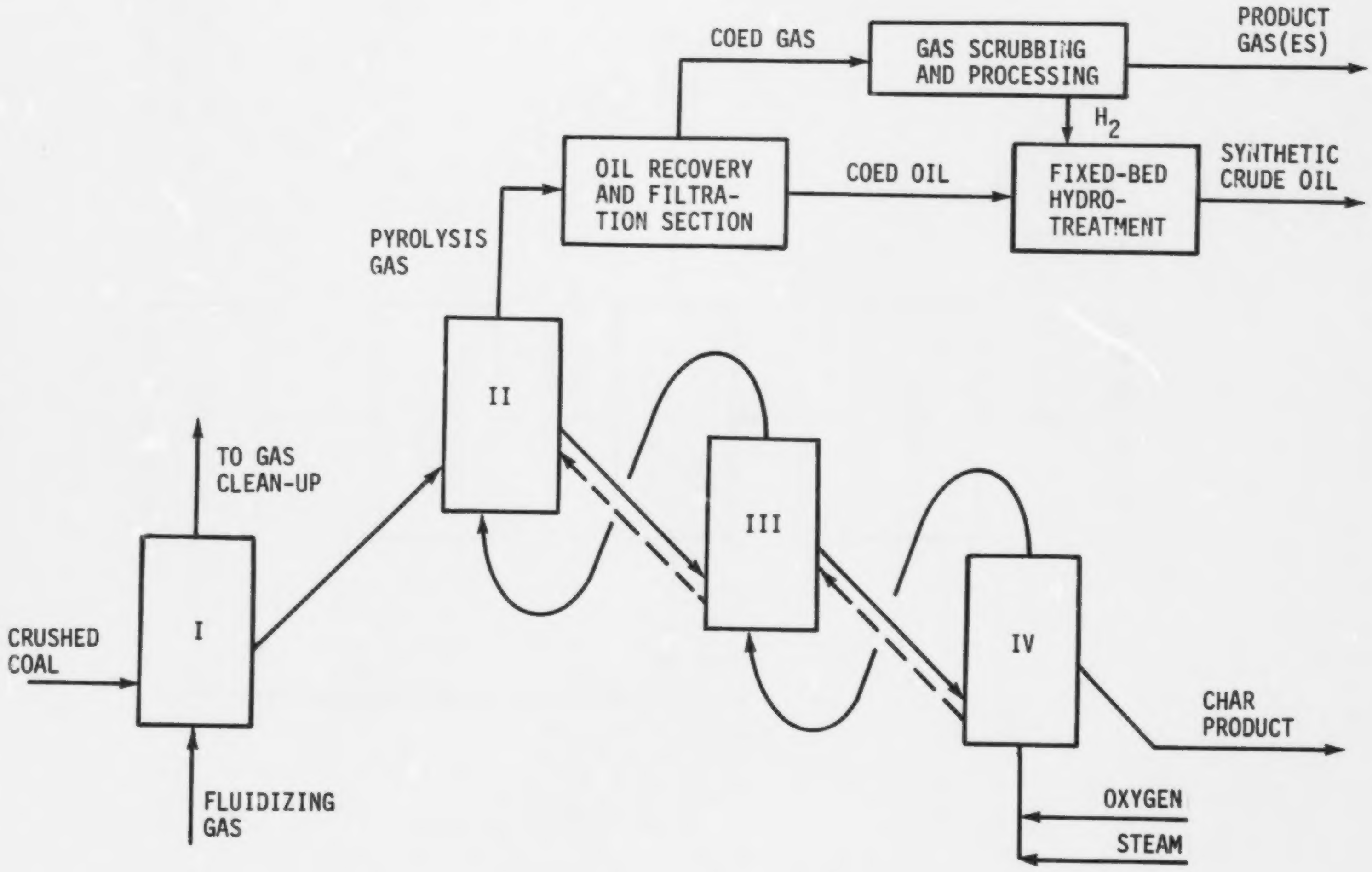


Figure 6. COED System

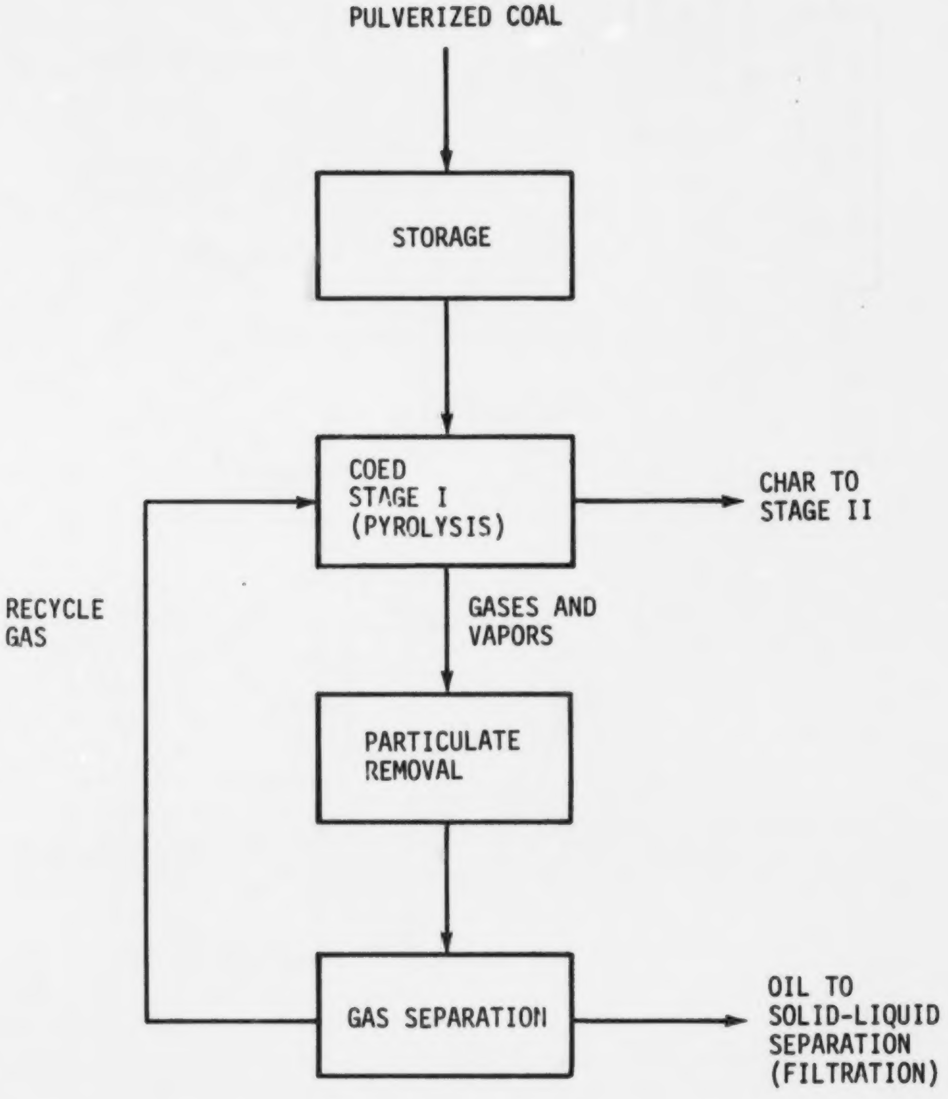


Figure 7. Stage I COED System

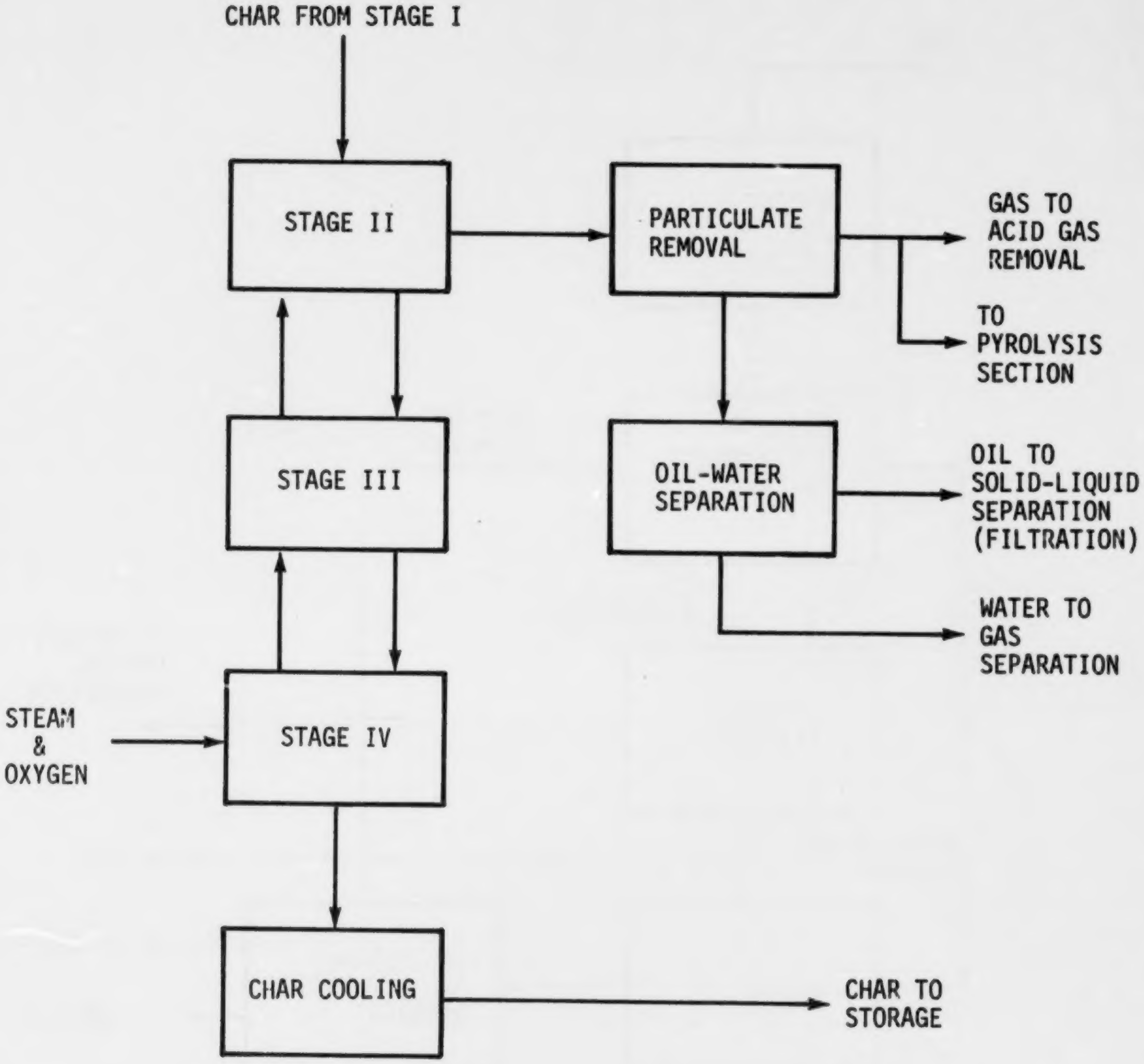


Figure 8. Stages II, III and IV COED System

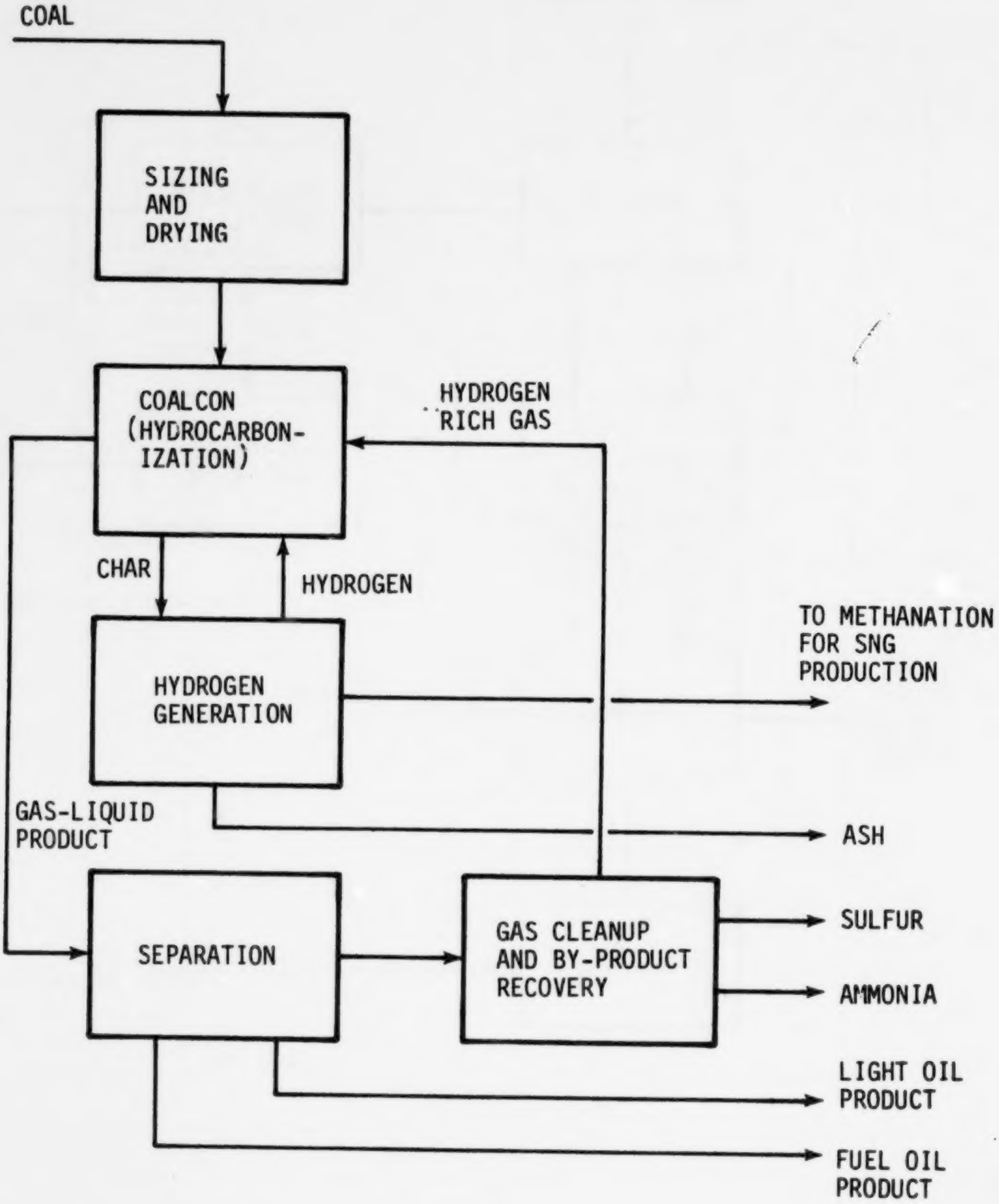


Figure 9. Coalcon System

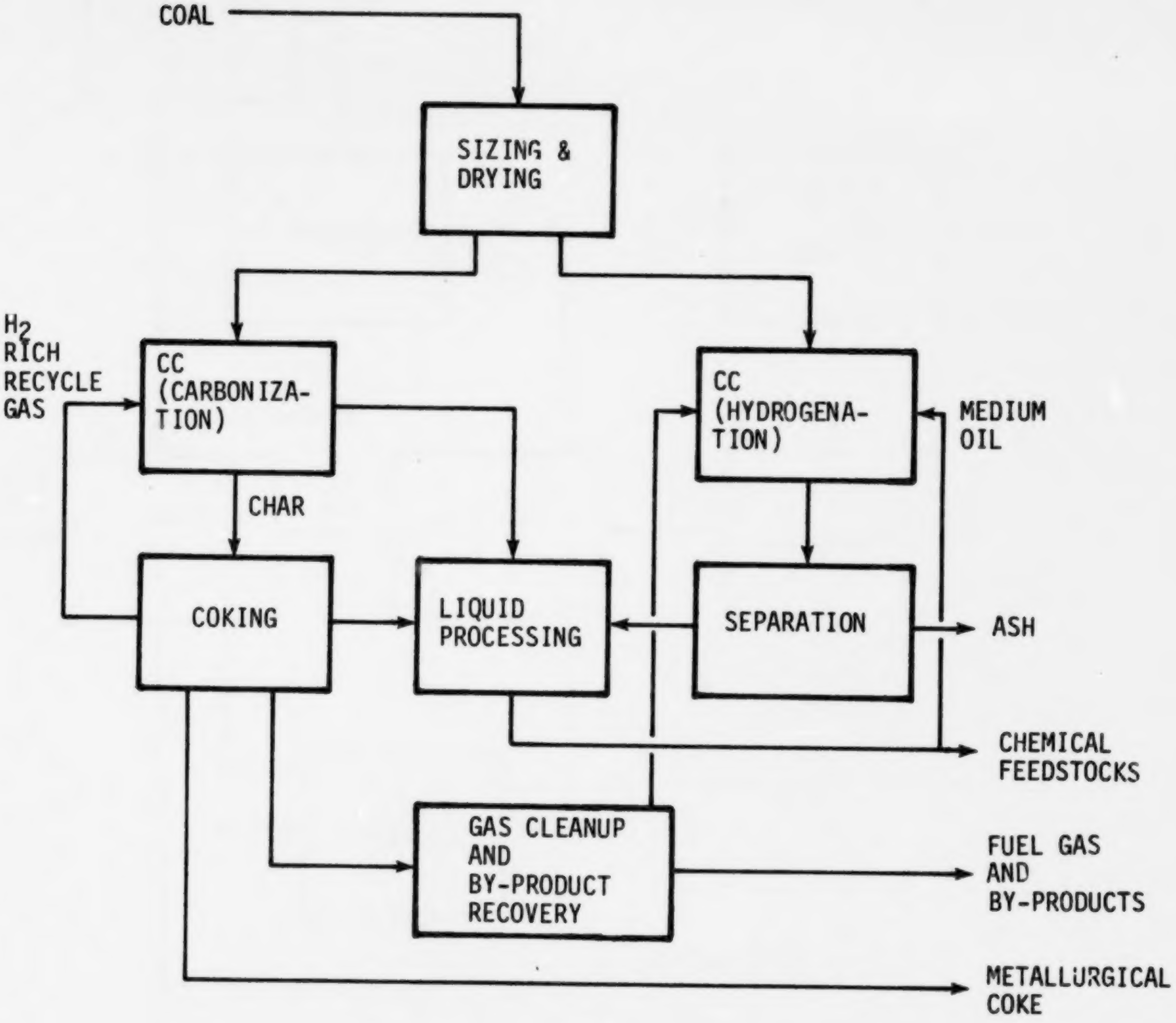


Figure 10. Clean Coke (CC) System

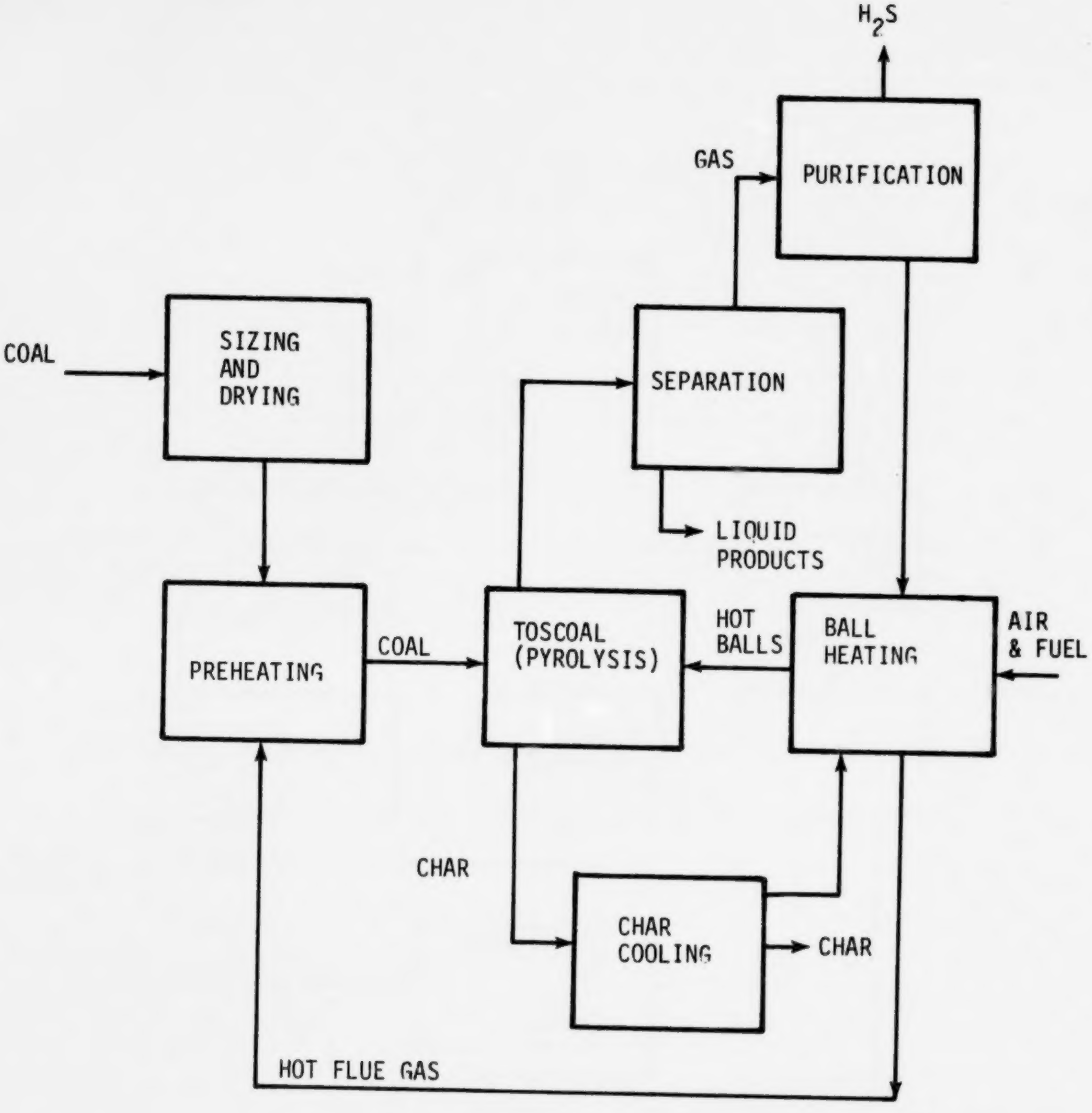


Figure 11. Toscoal System

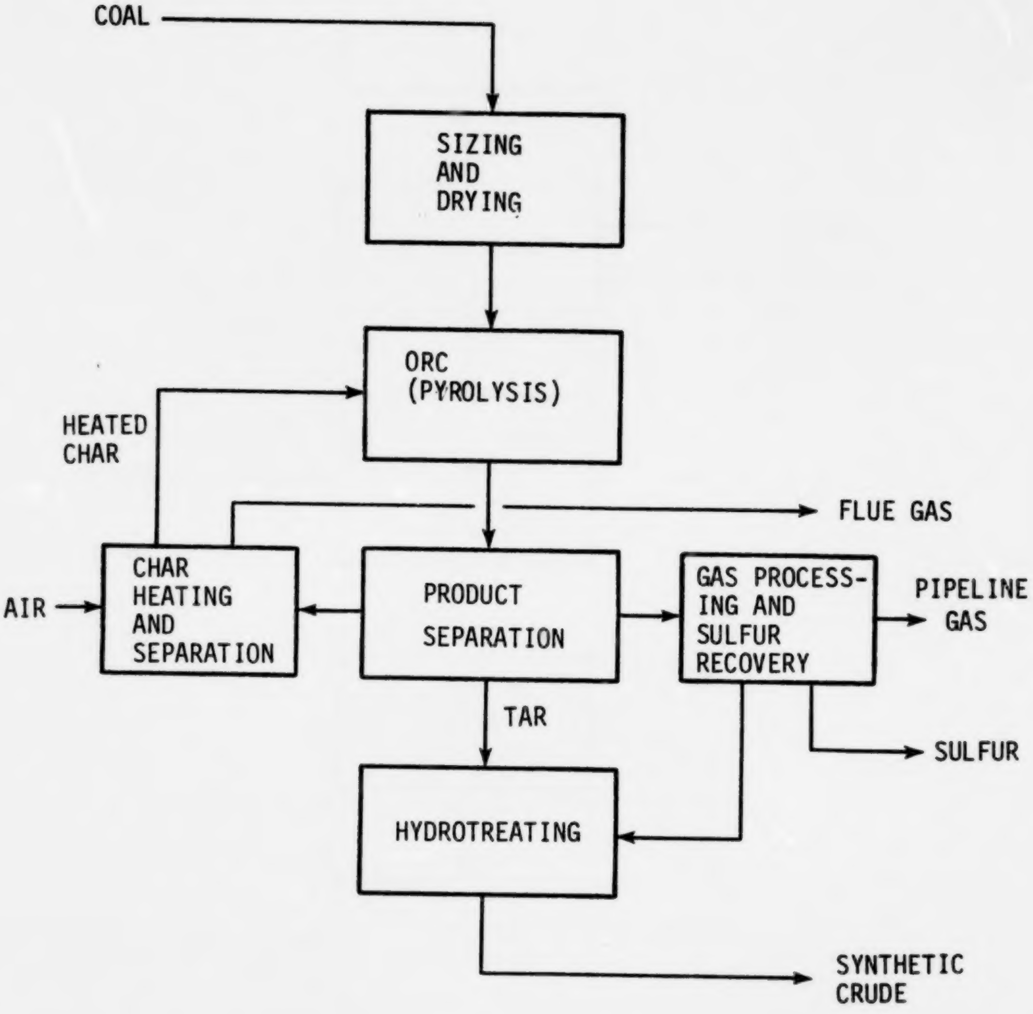


Figure 12. ORC System

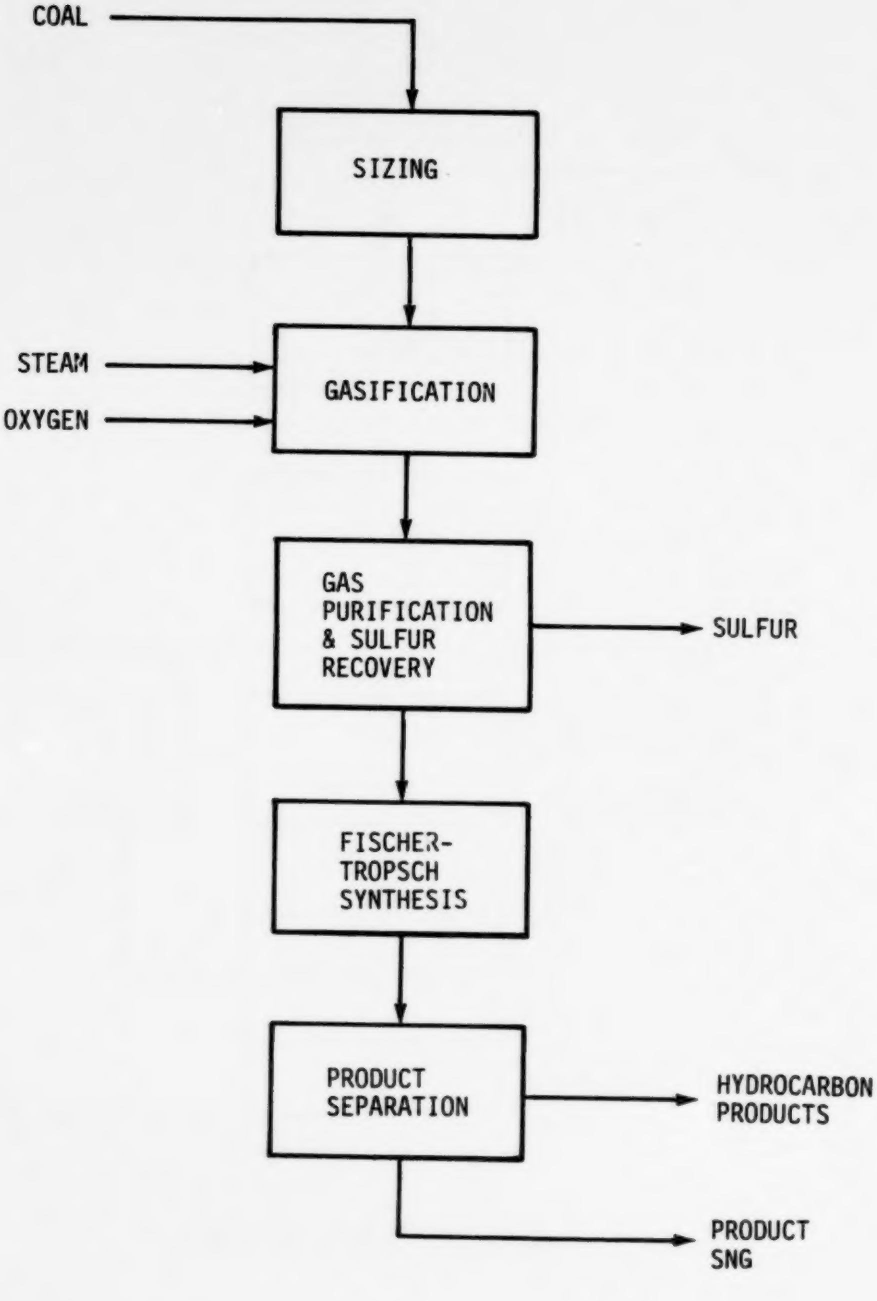


Figure 13. Fischer-Tropsch (F-T) System

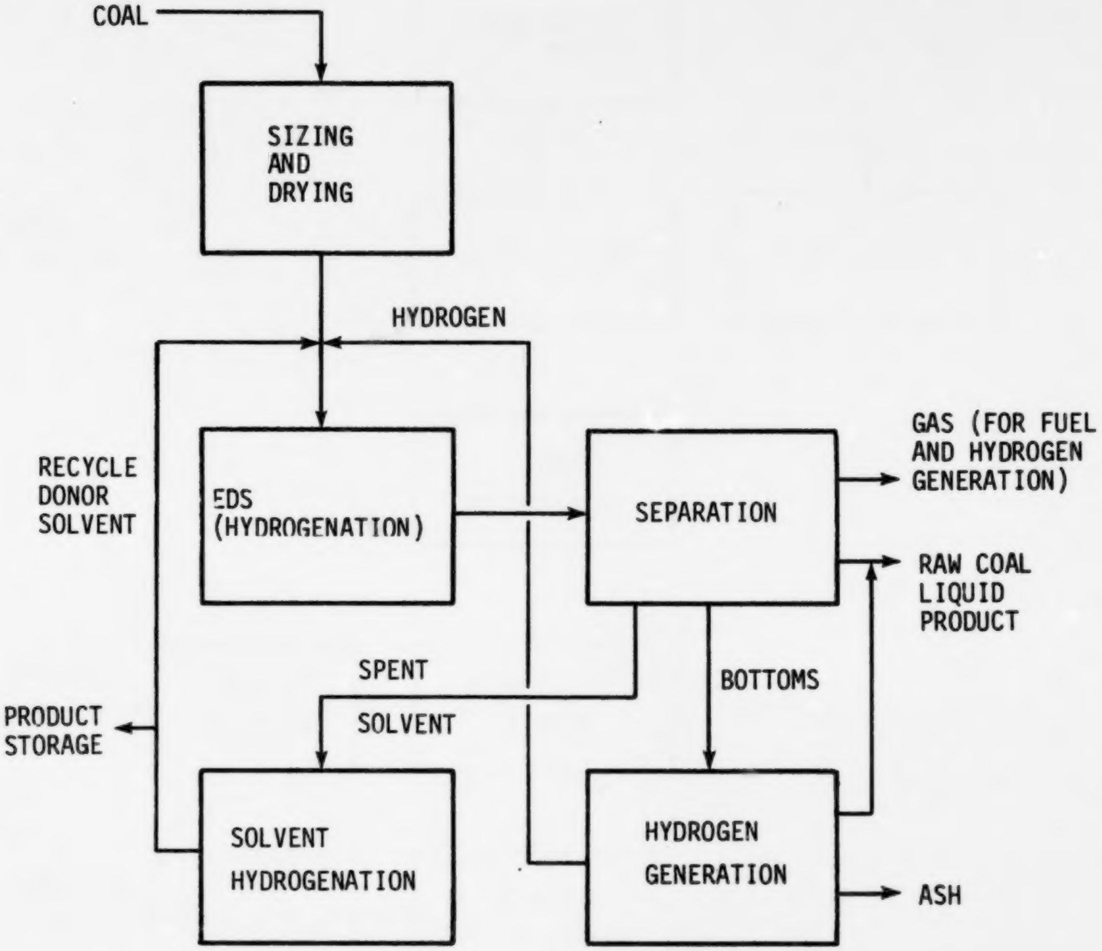


Figure 14. Exxon Donor Solvent (EDS) System

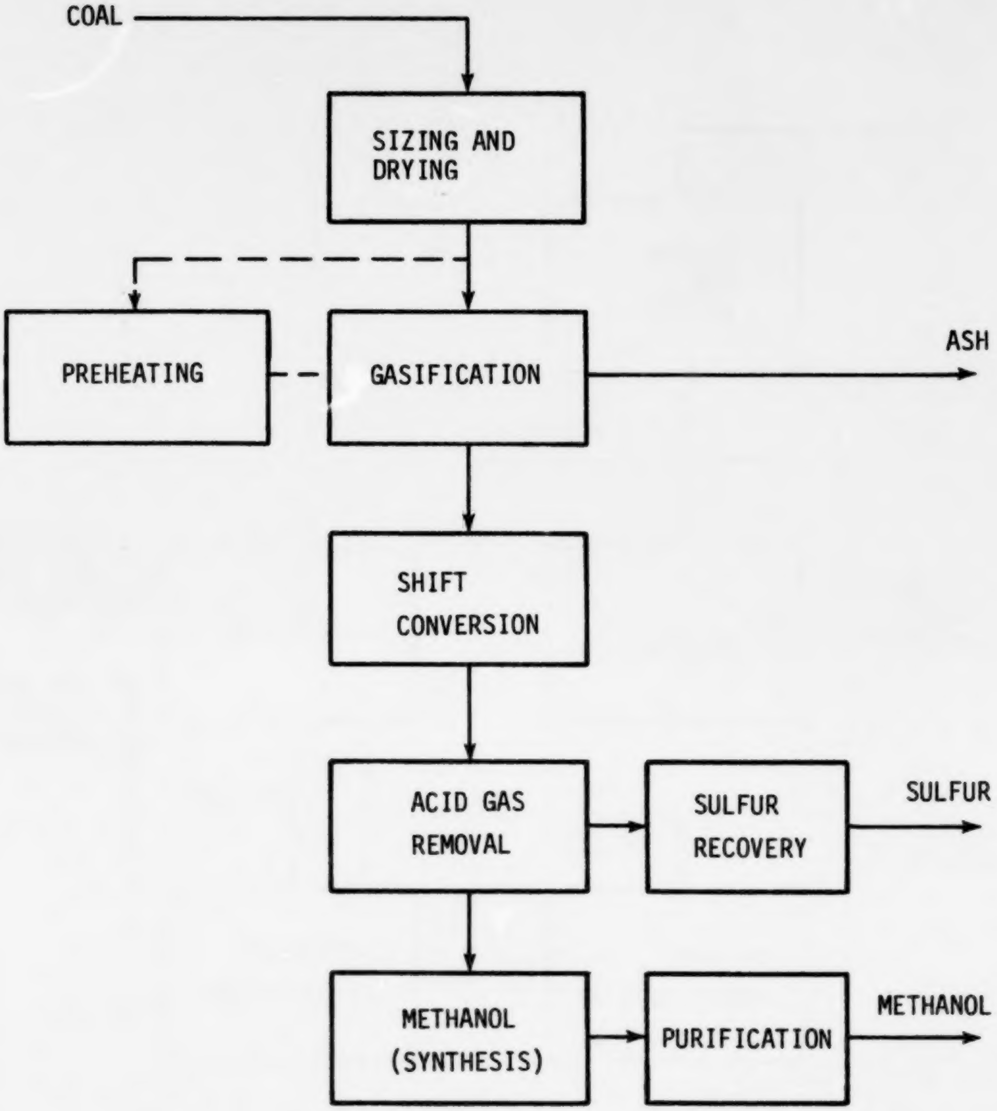


Figure 15. Mehtanol System

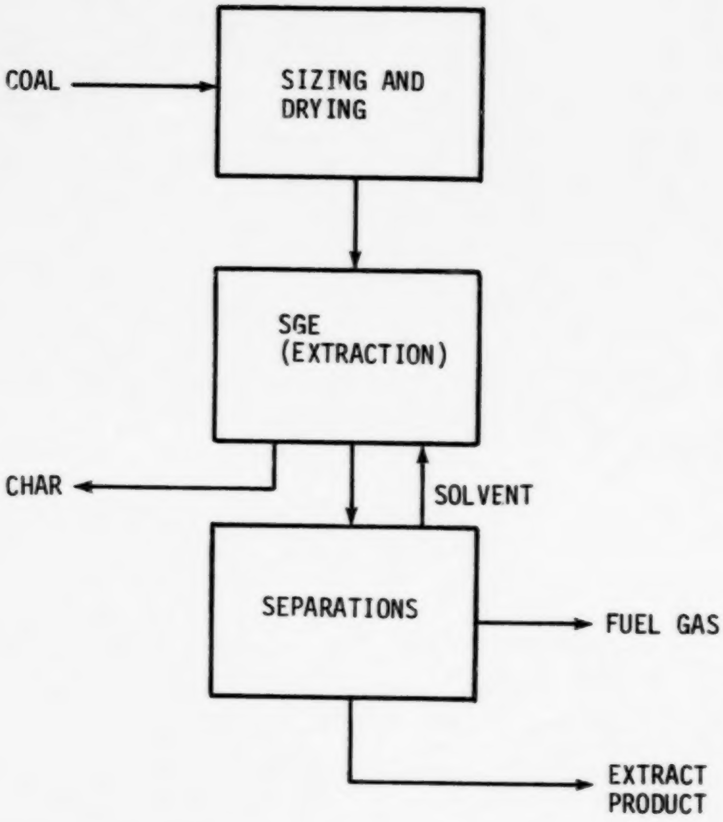


Figure 16. Supercritical Gas Extraction (SGE) System

APPENDIX B

Federal and Selected State Regulations

Key to symbols and abbreivations applicable to all tables of the Appendix.

max	denotes maximum
AAM	denotes Annual Arithemtic Mean
AGM	denotes Annual Geometric Mean
*	denotes that the maximum value is not to be exceeded more than once per year.
JTU	denotes Jackson Turbidity Units
COH/1000 LM	denotes Coefficient of Haze per 1000 linear meters
COH/1000 LF	denotes Coefficient of Haze per 1000 linear feet

Table 1. National Primary and Secondary Ambient Air Quality Standards

	Concentration		
Constituent	Metric	English	Remarks
Sulfur Oxides			
primary	80 ug/m^3	9.4x10^{-4}grain/yd^3	A.A.M.
	365 ug/m^3	4.3x10^{-3}grain/yd^3	24 hr max*
secondary	1300 ug/m^3	1.5x10^{-2}grain/yd^3	3 hr max*
Particulates			
primary	75 ug/m^3	8.8x10^{-4}grain/yd^3	A.G.M.
	260 ug/m^3	3.1x10^{-3}grain/yd^3	24 hr max*
secondary	60 ug/m^3	7.1x10^{-4}grain/yd^3	A.G.M.
	150 ug/m^3	1.8x10^{-3}grain/yd^3	24 hr max*
Carbon Monoxide			
primary and secondary	10 ug/m^3	0.12 grain/yd^3	8 hr max*
	40 ug/m^3	0.79 grain/yd^3	1 hr max*
Photochemical Oxidants			
primary and secondary	160 ug/m^3	1.9x10^{-3}grain/yd^3	1 hr max*
Hydrocarbons			
primary and secondary	160 ug/m^3	1.9x10^{-3}grain/yd^3	3 hr max* (6-9 A.M.)
Nitrogen Dioxide			
primary and secondary	100 ug/m^3	1.2x10^{-3}grain/yd^3	A.A.M.

Reference Conditions: Temperature = 25°C = 77°F

Pressure = 760 mm Hg = 29.92 in Hg = 1 atmosphere

Table 2. Federal New Source Performance Standards of Related Technologies

Coal Preparation - Particulates	Standard		
Type of Equipment	Metric	English	Opacity
Thermal Dryers	.057 mg/m^3	$2.2x10^{-4}$ $grain/yd^3$	20%
Coal Cleaning	.033 mg/m^3	$1.3x10^{-4}$ $grain/yd^3$	10%
Processing, Conveying and Storage	---------	--------------	20%

Fossil Fuel Steam Generators	Standard		
Constituent	Metric	English	Opacity
Particulates	0.17 $kg/10^6$ kcal	0.10 $lb/10^6$ Btu	20% (1)
Sulfur Dioxide (solid fuels)	2.07 $kg/10^6$ kcal	1.21 $lb/10^6$ Btu	----
Nitrogen Oxides (solid fuels)	1.21 $kg/10^6$ kcal	0.70 $lb/10^6$ Btu	----

Petroleum Liquid Storage Vessels	Vapor Pressure		
Constituent	Metric	English	Requirement
Hydrocarbons	78-570 mm Hg	3.0-22.4 in Hg	(2)
	570 mm Hg	22.4 in Hg	(3)

(1) 40% opacity allowed 2 minutes/hr

(2) floating roof or vapor recovery system or equivalent

(3) vapor recovery system or equivalent

Table 3 . Federal Effluent Guidelines and Standards for New Sources

Coal Preparation

Constituent	Concentration			
	1 day maximum		30 day average	
	mg/l	grain/gallon	mg/l	grain/gallon
Total Iron	7.0	0.41	3.5	0.20
Total Manganese	4.0	0.23	2.0	0.12
Total Suspended Solids	20.0	1.17	35.0	2.04

pH range: 6.0-9.0

By-Product Coking

Constituent	Concentration			
	1 day maximum		30 day average	
	kg/kkg	lb/ton	kg/kkg	lb/ton
Cyanide A	3×10^{-4}	7.26×10^{-4}	1×10^{-4}	2.42×10^{-4}
Phenol	6×10^{-4}	1.45×10^{-3}	2×10^{-4}	4.84×10^{-4}
Ammonia	1.26×10^{-2}	3.05×10^{-2}	4.2×10^{-3}	1.02×10^{-3}
Sulfide	3×10^{-4}	7.26×10^{-4}	1×10^{-4}	2.42×10^{-4}
Total Suspended Solids	3.12×10^{-2}	7.55×10^{-2}	1.04×10^{-2}	2.52×10^{-4}

pH range: 6.0-9.0

Table 4 . Some EPA Requirements and Recommendation for Solid Wastes

Aspect of Disposal	Requirement	Recommendations
Design	approval by professional engineer and responsible agency	analysis of solid waste materials; maintenance program; projection of subsquent use
Water Quality	compliance with Federal Water Pollution Control Act	projections of solid waste-soil-groundwater relationship
Air Quality	compliance with clean air act, state and local laws	dust control program
Gas Control	On site control of decomposition gases	preventing gas from concentrating to prevent explosions and toxicity hazards
Cover Material	cover shall be applied as necessary to minimize fire, odors, dust, etc.	minimum of 2 ft. final cover
Compaction	compaction to the smallest practicable volume	maximum depth of solid waste layers (2 ft)

Table 5 . Ambient Air Quality Standards in Alaska

Constituent	Maximum Concentration Allowed		Remarks
	Metric	English	
Particulates	60 ug/m^3	7.1×10^{-4} grain/yd^3	A.G.M.
	150 ug/m^3	1.8×10^{-3} grain/yd^3	24 hr max*
Sulfur Oxides	80 ug/m^3	9.4×10^{-4} grain/yd^3	A.A.M.
	365 ug/m^3	4.3×10^{-3} grain/yd^3	24 hr max*
	1300 ug/m^3	1.5×10^{-2} grain/yd^3	3 hr max*
Carbon Monoxide	10 ug/m^3	0.12 grain/yd^3	8 hr max
	40 ug/m^3	0.47 grain/yd^3	1 hr max
Photochemical Oxidants	160 ug/m^3	1.9×10^{-3} grain/yd^3	1 hr max
Nitrogen Dioxide	100 ug/m^3	1.2×10^{-3} grain/yd^3	A.A.M.
Reduced Sulfur Compounds	50 ug/m^3	6.0×10^{-4} grain/yd^3	30 min max

Reference Conditions: Temperature = 21°C = 70°F
Pressure = 1.03 kg/cm^2 = 14.7 psi = 1 atmosphere

Table 6. Emissions Standard for Industrial Processes and Fuel Burning Equipment in Alaska

Visible Emissions

20% opacity [+]

Particulate Matter	mg/m^3	$grain/ft^3$
(coal burning equipment)	4.24	0.05
	8.48	0.1

Sulfur Compounds (SO_2)

500 ppm

[+] denotes that the standard may not be exceeded for a total of more than three minutes in any hour.

Table 7 . Water Quality Criteria of Alaska

	Water Classification	
Parameter	Potable Water	Industrial Water
Dissolved Oxygen	75% saturation or 5 mg/l = 0.29 grain/gal	5 mg/l = 0.29 grain/gal for surface water
pH and (pH change)	6.5-8.5 (0.5 units)	6.5-8.5 (0.5 units)
Turbidity	5 JTU	No interference with water supply treatment
Temperature	16°C = 60°F	21°C = 70°F
Dissolved Inorganic Substances	500 mg/l = 29 grain/gal	low enough to prevent corrosion, scaling and process problems
Residues, Oils, Grease, Sludges, Other Physical and Chemical Criteria	essentially free from; may not exceed 1962 USPHS Standards (see Table 43)	No visible evidence of residue may not impact public health

Table 8 . Ambient Air Quality Standards of Arizona

Constituents	Concentration Metric	Concentration English	Remarks
Particulates	60 ug/m^3	$7.1x10^{-4}$grain/yd^3	A.G.M.
	150 ug/m^3	$1.8x10^{-3}$grain/yd^3	24 hr max
Sulfur Dioxide	50 ug/m^3	$6.0x10^{-4}$grain/yd^3	1 yr max
	260 ug/m^3	$3.1x10^{-3}$grain/yd^3	1 day max
	1300 ug/m^3	$1.5x10^{-2}$grain/yd^3	3 hr max
Non-Methane Hydrocarbons	160 ug/m^3	$1.9x10^{-3}$grain/yd^3	3 hr max (6-9 A.M.)
Photochemical Oxidants	160 ug/m^3	$1.9x10^{-3}$grain/yd^3	1 hr max
Carbon Monoxide	40 mg/m^3	0.47 grain/yd^3	1 hr max
	10 mg/m^3	0.12 grain/yd^3	8 hr max
Nitrogen Dioxide	100 ug/m^3	$1.2x10^{-3}$grain/yd^3	1 yr max

Air Quality Goals

Constituent	Metric	English	Remarks
Particulates	100 ug/m^3	$1.2x10^{-3}$grain/yd^3	24 hr max
Non-Methane Hydrocarbons	80 ug/m^3	$9.4x10^{-4}$grain/yd^3	3 hr max (6-9 A.M.)
Carbon Monoxide	7 mg/m^3	0.083 grain/yd^3	8 hr max
Photochemical Oxidants	80 ug/m^3	$9.4x10^{-4}$grain/yd^3	1 hr max

Standard Conditions: Temperature = 16°C = 60°F
Pressure = 1.03 kg/cm^2 = 14.7 psi

Table 9 . Industrial Emissions Standards in Arizona

Particulate Emissions - Process Industries - General

$E = 55.0\ p^{0.11} - 40$ ($E = 17.31\ p^{0.16}$ for Phoenix-Tucson Air Quality Control Region)

where

E = max allowable emissions rate (lb m/hr)
P = process weight rate (ton m/hr)

For commercial SRC plants

$$E = 55.0 \frac{20{,}000 \text{ ton/day}}{(24 \text{ hr/day})}^{11} - 40 = 75.2 \text{ lb m/hr} = 165.4 \text{ kg/hr}$$

$$E = 17.31\ p^{0.16} = 50.8 \text{ lb m/hr} = 111.9 \text{ kg/hr (Phoenix-Tucson)}$$

Sulfur - other industries

Requirement: a minimum of 90% removal

Storage of volatile organic compounds
(for storage capacities of 65,000 gallons or greater)

Requirement = A floating roof is required for compounds with vapor pressures greater than 2 lb in^2 but less than 12 lb/in^2. Equipment of equal efficiency may be substituted. The pressure range in metric units is from 0.1406 kg/cm^2 to 0.8436 kg/cm^2.

Table 10. Arizona Water Quality Criteria

Substance	Limiting Concentration mg/l	 grain/gallon
Arsenic	0.05	0.0029
Barium	1.0	0.0584
Cadmium	0.01	0.0006
Chromium (Hexavalent)	0.05	0.0029
Copper	1.0	0.0584
Cyanide	0.2	0.0117
Mercury	0.005	0.0003
Lead	0.05	0.0029
Phenol	0.001	5.8×10^{-5}
Selenium	0.01	0.0006
Silver	0.05	0.0029
Zinc	5.0	0.2921

For waters supporting aquatic life the following standards exist:

pH: 6.5 to 8.6 with no discharge causing a change in pH of more than 0.5 pH units.

Temperature: maximum temperature = 34°C = 93°F
maximum temperature increase = 2.8°C = 5°F

Table 11. Standards of Performance for Petroleum Refineries in Colorado

Particulates

1 kg/kkg = 1 lb/1000 lb

30% opacity for greater than 3 minutes in any hour is not allowed. Failure to comply due to uncombined water is not a violation.

Carbon Monoxide

Discharge gases may not contain greater than 0.050% carbon monoxide by volume.

Sulfur Dioxide

Emissions may not exceed those resulting from fuel gas containing 230 mg/dscm (0.10 grain/dscf) of hydrogen sulfide.

Table 12. Colorado Water Quality Standards

Standard	Water Classification A1	A2	B1	B2
Settleable Solids, Floating Solids, Taste, Odor, Color, and Toxic Materials	Free From	Free From	Free From	Free From
Oil and Grease	No film or discoloration	No film or discoloration	No film or discoloration	No film or discoloration
Turbidity Increase	10 J.T.U.	10 J.T.U.	10 J.T.U.	10 J.T.U.
Dissolved Oxygen (minimum)	6 mg/l 0.35 grain/ gallon	5 mg/l 0.29 grain/ gallon	6 mg/l 0.35 grain/ gallon	5 mg/l 0.29 grain/ gallon
pH Range	6.5-8.5	6.5-8.5	6.0-9.0	6.0-9.0
Temperature, Maximum	20°C 68°F	32°C 90°F	20°C 68°F	32°C 90°F
Temperature Maximum Increase	1.1°C 2°F	Streams 2.8°C 5°F Lakes 1.7°C 3°F	1.1°C 2°F	Streams 2.8°C 5°F Lakes 1.7°C 3°F

Table 13. Colorado Effluent Discharge Criteria

	7 day avg.		30 day avg.	
Parameter	mg/l	grain/gal.	mg/l	grain/gal.
BOD_5	45	2.63	30	1.75
Suspended Solids	45	2.63	30	1.75

Residual Chlorine	0.5 mg/l = 0.03 grain/gal.
Oil and Grease	10 mg/l = 5.84 grain/gal.
pH range	6.0 - 9.0

Table 14. Illinois Air Quality Standards

	Concentration		
Constituent	Metric	English	Remarks
Particulates			
primary	75 ug/m^3	8.8x10^{-4}grain/yd^3	A.G.M.
	260 ug/m^3	3.1x10^{-3}grain/yd^3	24 hr max*
secondary	60 ug/m^3	7.1x10^{-4}grain/yd^3	A.G.M.
	150 ug/m^3	1.8x10^{-3}grain/yd^3	24 hr max*
Non-Methane Hydrocarbon	160 ug/m^3	1.9x10^{-3}grain/yd^3	3 hr max* (6.9 A.M.)
Carbon Monoxide	10 ug/m^3	0.12 grain/yd^3	8 hr max*
	40 ug/m^3	0.47 grain/yd^3	1 hr max*
Nitrogen Dioxide	100 ug/m^3	1.2x10^{-3}grain/yd^3	A.A.M.
Photochemical Oxidants	160 ug/m^3	1.9x10^{-3}grain/yd^3	1 hr max*

Reference Conditions: Temperature = 25°C = 77°F
Pressure = 760 mm Hg = 29.92 in Hg

Table 15. New Process Emissions Standards in Illinois

Visible Emissions: 30% Opacity

Particules: $E = 24.8\ P^{0.16}$

where: E = allowable emissions rate in lb/hr
P = process wt rate in tons/hr

for an SRC facility processing 20,000 tons/day of coal,
E = 72.7 lb/hr = 33.1 kg/hr

Sulfur Dioxide: 2000 ppm

Hydrocarbons:

Storage: 85% control, pressurized tanks, or floating roofs for tanks greater than 151,400 liters (40,000 gallons)

Loading: 3.6 kg/hr (8 lb/hr) for throughputs exceeding 151,000 liters/day (40,000 gallons/day)

Hydrocarbon - Water Separators: 85% control if capacity exceeds 757 liters (200 gallons)

Table 16. Selected Water Quality Standards in Illinois

Parameter	Public Supply/Food Processing		Lake Michigan	
pH range	6.5 - 9.0		7.0 - 9.0	
	metric (mg/l)	English (grain/gal)	metric (mg/l)	English (grain/gal)
Dissolved oxygen(1)	6.0	0.3505	90%	
(2)	5.0	0.2921	of saturation	
Ammonia	1.5	0.0876	0.02	0.0012
Arsenic	0.01	5.84×10^{-4}	0.01	5.84×10^{-11}
Barium	1.0	0.0584	1.0	0.0584
Boron	1.0	0.0584	1.0	0.0584
Cadmium	0.01	5.84×10^{-4}	0.01	5.84×10^{-4}
Chloride	250	14.6029	12.0	0.7009
Chromium (hexavalent)	0.05	0.0029	0.05	0.0029
Chromium (trivalent)	1.0	0.0584	1.0	0.0584
Copper	0.02	0.0012	0.02	0.0012
Cyanide	0.01	5.84×10^{-4}	0.01	5.84×10^{-4}
Fluoride	1.4	0.0818	1.4	0.0818
Iron	0.3	0.0175	0.3	0.0178
Lead	0.05	0.0029	0.05	0.0029
Manganese	0.05	0.0029	0.05	0.0029
Mercury	0.0005	2.92×10^{-5}	0.0005	2.92×10^{-5}
Nickel	1.0	0.0584	1.0	0.0584
Phenol	0.001	5.84×10^{-5}	0.001	5.84×10^{-5}
Selenium	0.01	5.84×10^{-4}	0.01	5.84×10^{-4}
Silver	0.005	2.92×10^{-4}	0.005	2.92×10^{-4}
Sulfate	250	14.6029	24	1.4019
Total Dissolved Solids	500	29.2058	180	10.5141
Zinc	1.0	0.0584	1.0	0.0534
Oil	0.1	0.0058	0.1	0.0058

Table 16. Selected Water Quality Standards in Illinois (Continued)

Temperature varies with specific stream and the month of the year. Maximum temperatures for the Ohio River are as follows:

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Temp.°C	10	10	16	21	27	31	32	32	31	26	21	14
Temp.°F	50	50	60	70	80	87	89	89	87	78	70	57

Table 17. Illinois Effluent Standards

Constituent	mg/l	grains/gallon
Ammonia	3.0	0.175
Arsenic	0.25	0.015
Barium	2.0	0.117
Cadmium	0.15	8.76×10^{-3}
Chromium (hexavalent)	3.0	0.175
Chromium (trivalent)	1.0	0.058
Copper	1.0	0.058
Cyanide	0.025	1.46×10^{-3}
Fluoride	15.0	0.876
Iron (total)	2.0	0.117
Iron (dissolved)	0.5	0.030
Lead	0.1	5.84×10^{-3}
Manganese	1.0	0.058
Mercury	0.0005	2.92×10^{-5}
Nickel	1.0	0.058
Oil	15.0	0.876
Phenols	0.3	0.18
Phosphorous	1.0	0.058
Selenium	1.0	0.058
Silver	0.1	5.84×10^{-3}
Total Suspended Solids	15.0	0.876
Zinc	1.0	0.058

pH (range): 5-10

Table 18. Allowable Sound Pressure Levels in Illinois

Octave Band Center Frequency in Hertz	Allowable Octave Band Sound Pressure Level in Decibels	
	Daytime (1)	Nightime (2)
31.5	75	69
63	74	67
125	69	62.
250	64	54
500	58	47
1000	52	41
2000	47	36
4000	43	32
8000	40	32

(1) 7 A.M. - 10 P.M.

(2) 10 P.M. - 7 A.M.

Table 19. Indiana Ambient Air Quality Standards

Constituent	Concentration		Remarks
	Metric	English	
Sulfur Dioxide			
primary	80 ug /m^3	9.4×10^{-4}grain/yd^3	A.A.M.
	365 ug /m^3	4.3×10^{-3}grain/yd^3	24 hr max*
secondary	60 ug /m^3	7.1×10^{-3}grain/yd^3	A.A.M.
	260 ug /m^3	3.1×10^{-3}grain/yd^3	24 hr max*
	1100 ug /m^3	1.3×10^{-2}grain/yd^3	1 hr max*
Particulates			
primary	75 ug /m^3	8.8×10^{-4}grain/yd^3	A.G.M.
	260 ug /m^3	3.1×10^{-3}grain/yd^3	24 hr max*
secondary	60 ug /m^3	7.1×10^{-4}grain/yd^3	A.G.M.
	150 ug /m^3	1.8×10^{-3}grain/yd^3	24 hr max*
Carbon Monoxide			
primary and secondary	10 mg/m^3	0.12 grain/yd^3	8 hr max*
	40 mg/m^3	0.47 grain/yd^3	1 hr max*
Photochemical Oxidants			
primary and secondary	160 ug /m^3	1.9×10^{-3}grain/yd^3	1 hr max*
Hydrocarbons			
primary and secondary	160 ug /m^3	1.9×10^{-3}grain/yd^3	3 hr max* (6-9 A.M.)
Nitrogen Dioxide			
primary and secondary	100 ug /m^3	1.2×10^{-3}grain/yd^3	A.A.M.

Reference Conditions: Temperature = 25°C = 77°F
Pressure = 760 mmHg = 14.7 psi = 1 atmosphere

Table 20. Water Quality Criteria of Indiana

pH: between 6.0 and 8.5	
Toxic Substances:	shall not exceed one-tenth of the 96-hour median tolerance limit
Dissolved Oxygen:	5 mg/l daily average, never less than 4 mg/l (equivalent to 0.2921 grain/gal and 0.2336 grain/gal respectively)
Temperature:	Maximum Values Allowed

Month	Ohio River		St. Joseph River		Others	
	°C	°F	°C	°F	°C	°F
January	10	50	10	50	10	50
February	10	50	10	50	10	50
March	16	60	13	55	16	60
April	18	70	18	65	18	70
May	27	80	24	75	27	80
June	31	87	29	85	32	90
July	32	89	29	85	32	90
August	32	89	29	85	32	90
September	31	87	29	85	32	90
October	26	78	18	70	26	78
November	18	20	16	60	18	70
December	14	57	10	50	14	57

Maximum Temperature Rise is: 2.8 °C = 5°F for streams
1.7 °C = 3°F for lakes and reservoirs

(Note: certain parameters are more stringent for waters where natural reproduction of trout and salmon is to be protected.

Table 21. Ambient Air Quality Standards in Kentucky

	Concentration		
Constituent	Metric	English	Remarks
Sulfur Dioxide			
primary	80 ug/m^3	9.4x10^{-4} grain/yd^3	A.A.M.
	365 ug/m^3	4.3x10^{-3} grain/yd^3	24 hr max*
secondary	1300 ug/m^3	1.5x10^{-2} grain/yd^3	3 hr max*
Particulates			
primary	75 ug/m^3	8.8x10^{-4} grain/yd^3	A.G.M.
	260 ug/m^3	3.1x10^{-3} grain/yd^3	24 hr max*
secondary	60 ug/m^3	7.1x10^{-4} grain/yd^3	A.G.M.
	150 ug/m^3	1.8x10^{-3} grain/yd^3	24 hr max*
Particulates (Soiling Index)			
primary	19.7 COH/1000 LM	6.0 COH/1000 LF	24 hr max*
secondary	1.3 COH/1000 LM	0.4 COH/1000 LF	A.A.M.
	1.6 COH/1000 LM	0.5 COH/1000 LF	3 month max
	1.0 COH/1000 LM	0.3 COH/1000 LF	24 hr max*
Carbon Monoxide			
primary and secondary	10 ug/m^3	0.12 grain/yd^3	8 hr max*
	40 ug/m^3	0.47 grain/yd^3	1 hr max*
Photochemical Oxidants			
standard	160 ug/m^3	1.9x10^{-3} grain/yd^3	1 hr max*
Hydrocarbons			
standard	160 ug/m^3	1.9x10^{-3} grain/yd^3	3 hr max* (6-9 A.M.)
Nitrogen Dioxide			
standard	100 ug/m^3	1.2x10^{-3} grain/yd^3	A.A.M.

Table 21. Ambient Air Quality Standards in Kentucky (Continued)

Constituent	Concentration		Remarks
	Metric	English	
Hydrogen Sulfide			
standard	14 ug/m^3	$1.7\mathrm{x}10^{-4}$ grain/yd^3	1 hr max*
Gaseous Fluoride (HF)			
primary	0.82 ug/m^3	$9.7\mathrm{x}10^{-6}$ grain/yd^3	1 month max*
	1.64 ug/m^3	$1.9\mathrm{x}10^{-5}$ grain/yd^3	1 week max*
	2.86 ug/m^3	$3.4\mathrm{x}10^{-5}$ grain/yd^3	1 day max*
	3.68 ug/m^3	$4.3\mathrm{x}10^{-5}$ grain/yd^3	12 hr max*
Total Fluorides			
primary	40 ppm		6 month avg.
	60 ppm		2 month avg.
	80 ppm		1 month avg.

Reference Conditions: Temperature - 25°C = 77°F

Pressure = 760 mm Hg = 29.92 in Hg = 1 atm.

Table 22. Standards of Performance For Petroleum Refineries in Kentucky

Particulates

1.0 kg/kkg feed
1.0 lb/1000 lb feed

Carbon Monoxide

0.050% by volume

Sulfur Dioxide

Emissions may not exceed the equivalent of combustion of fuel gas containing 230 mg/dscm of hydrogen sulfide.

(230 mg/dscm = 0.10 grain/dscf)

Table 23. Kentucky Water Quality Standards

Constituent	Concentration mg/l	Concentration grain/gallon
Arsenic	0.05	0.0029
Barium	1.0	0.0584
Cadmium	0.01	5.84×10^{-4}
Chromium (hexavalent)	0.05	0.0029
Cyanide	0.025	0.0015
Fluoride	1.0	0.0584
Lead	0.05	0.0029
Selenium	0.01	5.84×10^{-4}
Silver	0.05	0.0029

Dissolved Oxygen: 5 mg/l = 0.2921 grain/gallon daily average
never the less than 4 mg/l = 0.2336 grain/gallon

Dissolved Solids: 500 mg/l = 29.21 grain/gal monthly average
never more than 700 mg/l = 40.89 grain/gal

Temperature: never to exceed 32°C = 89°F

Maxium Temperature Rise: 2.8°C = 5°F for streams, 1.7°C = 3°F for epilimnion of thermally stratificated waters

Maximum Monthly Temperature:

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°C	10	10	16	21	27	31	32	32	31	27	21	14
°F	50	50	60	70	80	87	89	89	87	78	70	57

Table 24. Ambient Air Quality Standards in Montana

Constituent	Concentration	Remarks
Sulfur Dioxide	0.02 ppm	A.A.M.
	0.10	(1)
	0.25	(2)
Hydrogen Sulfide	0.03 ppm	(3)
	0.05 ppm	(4)
Fluorides	1.0 ppb	24 hr max

	Metric	English	
Settled Particulates	5.26 kg/km^2/month	15 ton/mi^2/month	(5)
	10.53 kg/km^2/month	30 ton/mi^2/month	(6)
Reactive Sulfur (SO_3)	0.25 mg/100cm^2/day	0.036 grain/ft^2/day	A.A.M.
	0.50 mg/100cm^2/day	0.072 grain/ft^2/day	1 month max

	Metric (ug/m^3)	English (grain/yd^2)	
Total Suspended Particulates	75	8.8×10^{-4}	A.G.M.
	200	2.4×10^{-3}	(7)
Suspended Sulfate	4.0	4.7×10^{-5}	A.A.M.
	12.0	1.4×10^{-4}	(8)
Sulfuric Acid Mist	4.0	4.7×10^{-5}	A.A.M.
	12.0	1.4×10^{-4}	(8)
	30.0	3.5×10^{-4}	1 hr max (8)
Lead	5.0	5.9×10^{-5}	3 day max

(1) Not to be exceeded over 1% of the days in avg. 3 month period

(2) Not to be exceeded for more than one hour in avg. 4 consecutive days

(3) Not to be exceeded more than twice in avg. five consecutive days

(4) Not to be exceeded more than twice per year

(5) 3 month average - residential areas

(6) 3 month average - industrial areas

(7) Not to be exceeded more than 1% of the days in avg. year

(8) Not to be exceeded more than 1% of the time

Table 25. Selected Water Quality Criteria of Montana

Parameter	E-F Classification		A-Closed Classification
	Metric	English	
Dissolved Oxygen (minimum value)	3 mg/l	0.18 grain/gal	No decrease allowed
pH	6.5-9.5		No change allowed
pH variation allowed	0.5 pH units		Not allowed
Turbidity, Temperature, Sediments	Shall cause no adverse effects		No increase allowed
Toxic/Deleterious Substances	Less than demonstrated hazardous concentration		No increase allowed

Additionally, Montana waters shall comply with the 1962 U.S. Public Health Service Drinking Water Standards (see Table 48).

Table 26. New Mexico Emissions Standafds for Commerical Gasifiers

Constituent/Operation	Standard Metric	 English	Remarks
Particulates			
Briquetting	69 mg/scm	0.03 grain/scf	
General Operations	69 mg/scm	0.03 grain/scf	
Gas Burning Boilers	0.054 kg/10^6 Kcal	0.03 lb/10^6Btu	Based on heat input to boiler
Hydrogen Sulfide, Carbon Disulfide, Carbon Oxysulfide (Any Combination)			
General Operations	100 ppm (Total) 10 ppm (Hydrogen Sulfide)		All ppm by volume
Hydrogen Cyanide			
General Operations	10 ppm		
Hydrogen Chloride			
General Operations	5 ppm		
Ammonia			
General Operations	25 ppm		
Storage			Vapor control required
Sulfur Dioxide			
Gas Burning Boilers	0.29 kg/10^6 kcal	0.16 lb/10^6Btu	Based on heat input to boiler
Sulfur			
General Operations	0.014 kg/10^6kcal	0.008 lb/10^6Btu	Based on heat input of feed

Table 26. New Mexico Emissions Standards for Commercial Gasifiers (Continued)

Hydrocarbons

Storage - For a Reid vapor pressure greater than 0.1055 kg/cm^2 (1.5 psi) a floating roof, vapor recovery and disposal system or equivalent control technology is required.

Loading Systems - Vapor collection adapters are required.

Table 27. Ambient Air Quality Standards in New Mexico

Constituent	Concentration Metric	 English	Remarks
Particulates	150 ug/m^3	1.8×10^{-3}grain/yd^3	1 day max
	110 ug/m^3	1.3×10^{-3}grain/yd^3	7 day max
	90 ug/m^3	1.1×10^{-3}grain/yd^3	30 day max
	60 ug/m^3	7.1×10^{-4}grain/yd^3	A.G.M.
Heavy Metals	10 ug/m^3	1.2×10^{-4}grain/yd^3	
Soiling Index	1.3 COH/1000 LM	0.4 COH/1000 LF	
Sulfur Dioxide	0.10 ppm		24 hr max
	0.02 ppm		A.A.M.
Hydrogen Sulfide	0.003 ppm		1 hr max
	0.100 ppm		1/2 hr max (1)
Total Reduced Sulfur	0.003 ppm		1 hr max
Carbon Monoxide	8.7 ppm		8 hr max
	13.1 ppm		1 hr max
Nitrogen Dioxide	0.10 ppm		24 hr max
	0.05 ppm		A.A.M.
Photochemical Oxidants	0.10 ppm		24 hr max
	0.05 ppm		A.A.M.

(1) This standard applies to the Pecos-Permian Basin Instrastate Air Quality Control Region.

Emissions Standards for Refineries

Constituent	Concentration Metric	 English	Remarks
Mercaptan	0.11 kg/hr	0.25 lb/hr	
Carbon Monoxide	500 ppm		new facilities
	20,000 ppm		existing facilities

Table 28. New Mexico Water Quality Criteria

	Rio Grande Basin Section		San Fracisco River Basin Section		
Parameter	1	6	10	1	3
Dissolved Oxygen, mg/l	5.0	6.0 (1)	6.0 (1)	5.0	6.0 (1)
Dissolved Oxygen, grain/gallon	0.29	0.35(1)	0.35(1)	0.29	0.35(1)
pH Range	6.6-8.8	6.6-8.8	6.6-8.8	6.6-8.8	6.6-8.8
Temperature,°C	34	20	20	32.2	20
Temperature,°F	93.2	68	68	90	68
Total Dissolved Solids, mg/l	2000				
Total Dissolved Solids, grain/gallon	116.8				
Sulfates, mg/l	500				
Sulfates,grain/gallon	29.2				
Organic Carbon, mg/l			70		7.0
Organic Carbon,grain/gal			0.41		0.41

(1) denotes that 85% of saturation is alternatively allowable.

Table 29. Ambient Air Quality Standards of North Dakota

Constituent	Concentration		Remarks
	Metric	English	
Particulates	60 ug/m^3	7.1x10^{-4}grain/yd^3	A.G.M.
	150 ug/m^3	1.8x10^{-3}grain/yd^3	24 hr max*
Sulfur Dioxide	60 ug/m^3	7.1x10^{-4}grain/yd^3	A.A.M.
	260 ug/m^3	3.1x10^{-3}grain/yd^3	24 hr max
	715 ug/m^3	8.4x10^{-3}grain/yd^3	1 hr max
Hydrogen Sulfide	45 ug/m^3	5.3x10^{-4}grain/yd^3	1/2 hr max (1)
	75 ug/m^3	8.8x10^{-4}grain/yd^3	1/2 hr max (2)
Carbon Monoxide	10 mg/m^3	0.12 grain/yd^3	8 hr max*
	40 mg/m^3	0.47 grain/yd^3	1 hr max*
Photochemical Oxidants	160 ug/m^3	1.9x10^{-3}grain/yd^3	1 hr max*
Hydrocarbons	160 ug/m^3	1.9x10^{-3}grain/yd^3	1 hr max*
Nitrogen Dioxide	100 ug/m^3	1.2x10^{-3}grain/yd^3	A.A.M.
	200 ug/m^3	2.4x10^{-3}grain/yd^3	1 hr max (3)
Particulates (dustfall)	5.27 kkg/km^2/month	15 ton/mi^2/month	3 month max (4)
	10.53 kkg/km^2/month	30 ton/mi^2/month	3 month max (5)
Soiling Index	1.3 COH/1000 LM	0.4 COH/1000 LF	

(1) denotes that the maximum concentration is not to be exceeded more than twice in avg. five days

(2) denotes that the maximum concentration is not to be exceeded more than twice per year

(3) denotes that the maximum concentration is not to be exceeded more than one percent of the time in any three month period.

(4) applicable to residential areas

(5) applicable to industrial areas

Reference Conditions: Temperature = 25°C = 77°F
Pressure = 760 mmHg = 29.2 in Hg = 1 atm.

Table 30. Class I Water Quality Standards in North Dakota

	Maximum Allowable Concentration or Range	
Parameter	Metric (mg/l)	English (grain/gallon)
Ammonia	1.0	0.0584
Arsenic	0.05	0.0029
Barium	1.0	0.0584
Boron	0.5	0.0292
Cadmium	0.01	5.84×10^{-4}
Chlorides	100.0	5.8
Chromium (Total)	0.05	0.0029
Copper	0.05	0.0029
Cyanides	0.01	5.84×10^{-4}
Dissolved Oxygen (minimum)	5.0	0.2921
Lead	0.05	0.0029
Nitrates	4.0	0.2326
Phenols	0.01	5.84×10^{-4}
Phosphates	0.1	0.0058
Selenium	0.01	5.84×10^{-4}
Total Dissolved Solids	500.0	29.2
Zinc	0.5	0.0292
Temperature Increase	2.8°C	5°F
Maximum Temperature	29.4°C	85°F
pH	7.0-8.5	
Turbidity Increase	10 JTU	

Sodium: 50% of total cations as milliequivalents/liter

Table 31. Ohio Ambient Air Quality Standards

Constituent	Concentration Metric	 English	Remarks
Particulates	60 ug/m^3	7.1x10^{-4} grain/yd^3	A.G.M.
	150 ug/m^3	1.8x10^{-3} grain/yd^3	24 hr max*
Sulfur Dioxide	60 ug/m^3	7.1x10^{-4} grain/yd^3	A.G.M.
	260 ug/m^3	3.1x10^{-3} grain/yd^3	24 hr max*
Carbon Monoxide	10 mg/m^3	0.12	8 hr max*
Photochemical Oxidants	119 ug/m^3	1.4x10^{-3} grain/yd^3	1 hr max
	79 ug/m^3	9.5x10^{-4} grain/yd^3	4 hr max (1)
	40 ug/m^3	4.7x10^{-4} grain/yd^3	24 hr max*
Hydrocarbons	126 ug/m^3	1.5x10^{-3} grain/yd^3	3 hr max (2)
	331 ug/m^3	4.0x10^{-3} grain/yd^3	24 hr max*
Nitrogen Dioxide	100 /m^3	1.2x10^{-3} grain/yd^3	A.A.M.

(1) denotes the maximum concentration shall not be exceeded more than one consecutive four hour period per year.

(2) denotes that ambient levels are to be monitored from 6 to 9 A.M.

Reference Conditions: Temperature = 21.1°C = 70°F
(dry gas) Pressure = 1.03 kg/cm^2 = 14.7 psi

Table 32. Ohio Stream Quality Criteria for Public Water Supply Use

Constituent	Concentration	
	Metric (mg/l)	English (grain/gallon)
Arsenic	0.05	0.0029
Barium	1.0	0.0584
Cadmium	0.005	2.92×10^{-4}
Chromium (hexavalent)	0.05	0.0029
Cyanide	0.025	0.0015
Dissolved Oxygen (1)	5.0	0.2921
Dissolved Solids (2)	500	29.2
Fluoride	1.0	0.0584
Lead	0.05	0.0029
Mercury	0.005	2.92×10^{-4}
Selenium	0.005	2.92×10^{-4}
Silver	0.05	0.0029

(1) Dissolved oxygen concentration are minimum values. The given values are averages. A value of 4.0 mg/l (0.2336 grain/gallon) is the minimum acceptable value. These values are for waters designated to support aquatic life.

(2) Value given is monthly average with a maximum allowable value of 750 mg/l (43.8 grain/gallon) never to be exceeded.

Table 33. General Water Standards Applicable Within 500 Yards of Any Public Water Supply Intake in Ohio

Constituent	Concentration Limit	
	Metric (mg/l)	English (grain/gallon)
Cyanide	0.005	2.92×10^{-4}
Dissolved Iron	0.3	0.0175
Dissolved Manganese	0.05	0.0029
Dissolved Oxygen (1)	5.0	0.2921
Dissolved Solids (2)	500	29.2
Hexavalent Chromium	0.01	5.84×10^{-4}
Nitrates	8.0	0.4673
Phenols	0.001	5.84×10^{-5}
pH Range	6.0-9.0	

(1) 5.0 mg/l (0.2921 grain/gallon) daily minimum average, never less than 4.0 mg/l (0.2336 grain/gallon).

(2) Dissolved solids level may exceed (a) or (b) but not both.

  (a) 500 mg/l (29.2 grain/gallon) monthly average, never to exceed 750 mg/l (43.8 grain/gallon).

  (b) 150 mg/l (8.8 grain/gallon) attributable to human activities.

Table 34. Ambient Air Quality Standards of Pennsylvania

Constituent	Concentration		Remarks
	Metric	English	
Settled Particulates	0.8 ug/cm^2/month	grain/in^2/month	A.A.M.
	1.5 ug/cm^2/month	grain/in^2/month	30 day max
Lead	5.0 ug/m^3		30 day max
Sulfates	1.0 ug/m^3		30 day max
	3.0 ug/m^3		24 hr max
Fluorides	5.0 ug/m^3		24 hr max
Hydrogen Sulfide		0.005 ppm	24 hr max
		0.1 ppm	1 hr max

Standards for Contaminants

Particulates - unspecified process

For effluent gas discharge rates greater than 8500 dscm/min (300,000 dscf/min), 458 mg/dscm (0.2 grain/dscf) is allowed.

Particulates - petroleum refineries

20 kg/kkg (40 lb/ton) of liquid feed

Visible Emissions - unspecified process

Opacity equal to or greater than 20% is not allowed for aggregate periods of more than three minutes in any hour. Additionally, 60% opacity may never be exceeded. Opacity due to uncombined water mists is excluded in determining opacity levels.

Table 35. Water Quality Standards for the Monongahela River in Pennsylvania

Parameter	Concentration Metric	 English
Dissolved Oxygen (1)	6.0 mg/l	0.3505 grain/gallon
Total Iron	1.5 mg/l	0.0876 grain/gallon
Maximum Temperature	30.6°C	87°F
Temperature Increase (2)	2.8°C	5°F
Dissolved Solids (3)	500 mg/l	29.2 grain/gallon
Total Manganese	1.0 mg/l	0.0584 grain/gallon
Phenols	0.005 mg/l	2.92×10^{-4}grain/gallon
pH Range	6.0-8.5	

(1) 6.0 mg/l (0.3505 grain/gallon) is the minimum daily average. 5.0 mg/l (0.2921 grain/gallon) is the minimum acceptable level. For the epilimnion of stream sections where the rural statisifcation occurs, the minimum daily average is 5.0 mg/l (0.2921 grain/gallon) and the minimum acceptable level is 4.0 mg/l (0.2336 grain/gallon)

(2) A 5°F temperature rise may not cause a resulting stream temperature of greater than 30.6°C (87°F). Also, a maximum hourly temperature change of 1.1°C (2°F) is allowed.

(3) 500 mg/l (29.2 grain/gallon) is the monthly average. 750 mg/l (43.8 grain/gallon) may never be exceeded.

Table 36. Ambient Air Quality Standards of South Dakota

Constituent	Concentration Metric	Concentration English	Remarks
Sulfur Oxides	60 mg/m^3	$7.1x10^{-4}$grain/yd^3	A.A.M.
	260 mg/m^3	$3.1x10^{-3}$grain/yd^3	24 hr max*
Particulates	60 mg/m^3	$7.1x10^{-4}$grain/yd^3	A.G.M.
	150 mg/m^3	$1.8x10^{-3}$grain/yd^3	24 hr max*
Soil Index	0.66 COH/1000LM	0.20 COH/1000 LF	A.G.M.
Carbon Monoxide	10 mg/m^3	0.12 grain/yd^3	8 hr max*
	15 mg/m^3	0.18 grain/yd^3	1 hr max*
Photochemical Oxidants	125 mg/m^3	$1.5x10^{-3}$grain/yd^3	1 hr max*
Hydrocarbons	125 mg/m^3	$1.5x10^{-3}$grain/yd^3	3 hr max* (1)
Nitrogen Oxides	100 mg/m^3	$1.2x10^{-3}$grain/yd^3	A.A.M.
	250 mg/m^3	$2.9x10^{-3}$grain/yd^3	24 hr max*

(1) Monitored from 6-9 A.M.

Standard Conditions: Temperature = 20°C = 68°F
Pressure = 760 mmHg = 29.92 inHg = 1 atmosphere

Table 37. Selected South Dakota Industrial Emissions Standards

Fuel Burning Installations

Particulates

0.54 kg/kcal of heat input = 0.30 lb/10^6 Btu of heat input

Sulfur Oxides

5.4 kg/kcal of heat input = 3.0 lb/10^6 Btu of heat input

Nitrogen Oxides

0.36 kg/kcal of heat input = 0.2 lb/10^6 Btu of heat input

General Process Industries

Particulates

$E = 55.0\ p^{0.11} - 40$

where E = rate of emission in lb/hr
P = process weight rate in ton/hr

(Note: Same equation is applicable in Arizona).

Table 38. Applicable Water Quality Standards of South Dakota

Parameter	Concentration Metric	 English	Water Use	Remarks
Total Dissolved Solids	1000 mg/1 2000 mg/1	58.4 grain/gal 116.8 grain/gal	Domestic Supply Industrial Supply	
Nitrates	10 mg/1	0.5841 grain/gal	Domestic Supply	As N
Nitrates	45 mg/1	2.6285 grain/gal	Domestic Supply	As NO_3
Ammonia	0.6 mg/1	0.0350 grain/gal	Domestic Supply	
Chlorides (1)	100 mg/1	5.84 grain/gal	Domestic Supply	
Cyanides (total)	0.02 mg/1	0.0012 grain/gal	Domestic Supply	
Cyanides (free)	0.005 mg/1	2.92×10^{-4} grain/gal	All	
Dissolved Oxygen	6.0 mg/1	0.3505 grain/gal	Cold	minimum concentratio
Dissolved oxygen	7.0 mg/1	0.4089 grain/gal	Water	Spawning season
Hydrogen Sulfide	0.002 mg/1	1.17×10^{-4} grain/gal	Fish	
Suspended Solids	30 mg/1	1.75 grain/gal	Propagation	
Total Iron	0.2 mg/1	0.0117 grain/gal		
Temperature	18.3°C	65°F		
Turbidity	10JTU			

(1) Additionally total chlorine is limited to 0.2 mg/1 (0.0117 grain/gal).

Table 39. Texas Air Regulations

Ambient Air Quality Standards for Hydrogen Fluoride

4.5 ppb	12 hr max
3.5 ppb	24 hr max
2.0 ppb	7 day max
1.0 ppb	30 day max

Net Ground Level Concentrations for Applicable Emissions

Constituent	Concentration	Remarks
Hydrogen Sulfide (1)	0.08 ppm	30 min max
	0.12 ppm	30 min max

	Metric (ug/m^3)	English (grain/yd^3)	
Sulfuric Acid	15	1.8×10^{-4}	24 hr max
	50	5.9×10^{-4}	1 hr max (2)
	100	1.2×10^{-3}	max allowed
Particulates	100	1.2×10^{-3}	5 hr max
	200	2.4×10^{-3}	3 hr max
	400	4.7×10^{-3}	1 hr max

(1) The first value is applicable only when residential areas are downwind of the source of emissions.

(2) Denotes that the maximum value is not to be exceeded more than once per 24 hour period.

Table 39. Continued

Emissions Limits for Fuel Burning Steam Generators (3)

Constituent	Concentration		Remarks
	Metric	English	
Particulates	0.54 kg/10^6kcal	0.3 lb/10^6 Btu	24 hr max (4)
	0.18 kg/10^6kcal	0.1 lb/10^6 Btu	2 hr max (5)
Sulfur Dioxide	5.40 kg/10^6kcal	3.0 lb/10^6 Btu	
Nitrogen Oxides	1.26 kg/10^6kcal	0.7 lb/10^6 Btu	2 hr max (6)
	0.90 kg/10^6kcal	0.5 lb/10^6 Btu	2 hr max
	0.45 kg/10^6kcal	0.25 lb/10^6Btu	2 hr max

(3) applicable for heat inputs greater than 2500 million Btu/hr.

(4) solid fuel burners

(5) gas and liquid fuel burners

(6) standards apply to opposed fired, front fired and tagential fired steam generators respectively.

Table 40. Water Uses and Quality Criteria for the San Antonio River Basis

Water Use/Quality Parameter	1	2	3	4	5
Contact Recreation	N	O	U	U	U
Non-Contact Recreation	U	U	U	U	U
Fish and Wildlife	U	U	U	U	U
Domestic Supply	U	U	U	U	U
Chlorides, mg/l	200	200	40	120	50
Chlorides grain/gal	11.7	11.7	2.3	7.0	2.9
Sulfates, mg/l	150	300	75	120	75
Sulfates grain/gal	8.8	17.5	4.4	7.0	4.4
Total Dissolved Solids, mg/l	700	900	400	700	400
Total Dissolved Solids, grains/gal	40.9	52.6	23.4	40.9	23.4
pH range	6.5-8.5	7.0-9.0	7.0-9.0	7.0-9.0	7.0-9.
Temperature, °C	32	32	32	32	32
Temperature, °F	90	90	90	90	90
Dissolved oxygen, mg/l	5.0	5.0	5.0	5.0	5.0
Dissolved oxygen, grain/gal	0.29	0.29	0.29	0.29	0.29

N	denotes not currently useable
O	denotes not currently useable, quality to be improved
U	Denotes useable for given water use

(1) San Antonio River
(2) Cibolo Creek (Section 1)
(3) Cibolo Creek (Section 2)
(4) Medina River (Section 1)
(5) Medina River (Section 2)
(6) Medina Lake
(7) Medina River (Section 3)
(8) Leon Creek (Section 1)
(9) Leon Creek (Section 2)

Table 40. (continued)

Water Use/Quality Parameter	6	7	8	9
Contact Recreation	U	U	U	U
Non-Contact Recreation	U	U	U	U
Fish and Wildlife	U	U	U	U
Domestic Supply	U	U	U	U
Chlorides, mg/l	50	40	120	40
Chlorides grain/gal	2.9	2.3	7.0	2.3
Sulfates, mg/l	75	100	120	75
Sulfates grain/gal	4.4	5.8	7.0	4.4
Total Dissolved Solids, mg/l	400	400	700	400
Total Dissolved Solids, grains/gal	23.4	23.4	40.9	23.4
pH range	7.0-9.0	7.0-9.0	7.0-9.0	7.0-9.0
Temperature, °C	31	31	35	35
Temperature, °F	88	88	95	95
Dissolved oxygen, mg/l	5.0	5.0	5.0	5.0
Dissolved oxygen, grain/gal	0.29	0.29	0.29	0.29

Table 41. Water Criteria for Class "A" Utah Waters (From Public Health Service Drinking Water Standards, 1962)

Turbidity: 5 JTU

Chemical Constituent	Concentration	
	Metric (mg/l)	English (grain/gal)
Arsenic	0.01	5.84×10^{-4}
Chlorides	250	14.6
Copper	1.0	0.0584
Cyanide	0.01	5.84×10^{-4}
Fluoride (1)	1.7	0.0993
Iron	0.3	0.0175
Manganese	0.05	0.0029
Nitrates	45	2.63
Phenols	0.001	5.84×10^{-5}
Sulfates	250	14.6
Total Dissolved Solids	500	29.2
Zinc	5.0	0.2921

(1) Fluoride concentrations is temperature dependent, the given value being the maximum allowed at temperatures below 10°C (50°F).

Table 42. Applicable Air Pollution Regulations In West Virginia

Coal Preparation, Drying and Handling

Particulates - for volumetric flow rates greater than 14,200 scm/m (500,000 scf/min.) the allowable emission rate is 0.18 gm/scm (0.08 grain/scf).

Manufacturing Process Operations

Particulates - for process weight rates exceeding 45,500 kg/hr (100,000 lb/hr) the allowable emission rate is 9.6 kg/hr (21.2 lb/hr)

Smoke - No smoke darker than No. 1 on the Ringelmann Smoke Chart is permitted. No smoke darker than No. 2 on the Ringelmann Smoke Chart is permitted for more than five minutes in any sixty minute period.

Table 43. West Virginia Air Quality Standards

Constituent	Concentration Metric	 English	Remarks
Sulfur Dioxide			
primary	80 mg/m^3	$9.4x10^{-4}$grain/gal	A.A.M.
	365 mg/m^3	$4.3x10^{-3}$grain/gal	24 hr max*
secondary	1300 mg/m^3	$1.5x10^{-2}$grain/gal	3 hr max*
Particulates			
primary	75 mg/m^3	$8.8x10^{-4}$grain/gal	A.G.M.
	260 mg/m^3	$3.1x10^{-3}$grain/gal	24 hr max*
secondary	60 mg/m^3	$7.1x10^{-4}$grain/gal	A.G.M.
	150 mg/m^3	$1.8x10^{-3}$grain/gal	24 hr max*
Carbon Monoxide			
standard	10 mg/m^3	0.12 grain/gal	8 hr max*
	40 mg/m^3	0.47 grain/gal	1 hr max*
Photochemical Oxidants			
standard	160 mg/m^3	$1.9x10^{-3}$grain/gal	1 hr max*
Non-Methane Hydrocarbons	160 mg/m^3	$1.9x10^{-3}$grain/gal	3 hr max* (6-9 A.M.)

Standard Conditions: Temperature = 25°C - 77°F

Pressure = 760 mmHg = 29.92 in Hg = 1 atmosphere

Table 44. Water Quality Criteria for the Gauley River and Tributaries in West Virginia

Dissolved Oxygen: never less than 5.0 mg/l = 0.2921 grain/gallon

pH Range : 6.0 - 8.5

Temperature: Maximum increase 2.8°C = 5°F

Maximum Temperature

27°C = 81°F (May-November)

23°C = 73°F (December-April)

Chemical Constituent	Maximum Concentration	
	Metric (mg/l)	English (grain/gal)
Arsenic	0.01	5.84×10^{-4}
Barium	0.50	0.0292
Cadmium	0.01	5.84×10^{-4}
Chloride	100	5.84
Chromium (hexavalent)	0.05	0.0029
Cyanide	0.025	0.0015
Fluoride	1.0	0.0584
Lead	0.05	0.0029
Nitrates	45	2.63
Phenol	0.001	5.84×10^{-5}
Selenium	0.01	5.84×10^{-4}
Silver	0.05	0.0029

Table 45. Wyoming Ambient Air Standards

Constituent	Concentration Metric	English	Remarks
Particulates	60 mg/m^3	7.1x10^{-4}grain/gal	A.G.M.
	150 mg/m^3	1.8x10^{-3}grain/gal	24 hr max*
Soiling Index	1.3 COH/1000	0.4 COH/1000 LF	A.G.M.
Total Settleable Particulates	5 g/m^2/month	59 grain/yd^2/month	(1)
	10 g/m^2/month	118 grain/yd^2/month	
Sulfur Oxides	60 mg/m^3	7.1x10^{-4}grain/gal	A.A.M.
	260 mg/m^3	3.1x10^{-3}grain/gal	24 hr max*
	1300 mg/m^3	1.5x10^{-2}grain/gal	3 hr max*
Hydrogen Sulfide	70 mg/m^3	8.3x10^{-4}grain/gal	1/2 hr max (2)
	40 mg/m^3	4.7x10^{-3}grain/gal	1 hr max*
Photochemical Oxidants	160 mg/m^3	1.9x10^{-3}grain/gal	1 hr max*
Hydrocarbons	160 mg/m^3	1.9x10^{-3}grain/gal	3 hr max* (3)
Nitrogen Oxides	100 mg/m^3	1.2x10^{-3}grain/gal	A.A.M.
Fluorides	1 ppb		24 hr max
Carbon Monoxide	10 mg/m^3	0.12 grain/gal	8 hr max*
	40 mg/m^3	0.47 grain/gal	1 hr max*

Standard Conditions: Temperature = 21°C = 70°F
Pressure = 760 mmHg = 29.92 in.Hg = 1 atmosphere

(1) Values given include 1.7 g/m^2/month (20.1 grain/yd^2/month) background settled particulates

(2) Hydrogen sulfide values are not to be exceeded more than twice per year.

(3) Monitored 6-9 A.M.

Table 46. Applicable Wyoming Emissions Regulations

New Fuel Burning Equipment - Sulfur Dioxide

$0.36\ \mathrm{kg}/10^6\,\mathrm{Kcal}$ input = $0.20\ \mathrm{lb}/10^6$ Btu input

(applicable to coal burners)

New Fuel Burning Equipment - Nitrogen Oxides

$1.26\ \mathrm{kg}/10^6\,\mathrm{Kcal}$ input = $0.70\ \mathrm{lb}/10^6$ Btu input

(applicable to non-lignite coal burners)

Stationary Sources - Carbon Monoxide Requirement

Stack gases shall be treated by direct flame after burner as required to prevent ambient standards from being exceeded.

Stationary Sources - Hydrogen Sulfide Requirement

Gases containing hydrogen sulfide shall be vented, incinerated, or flared as necessary to ambient standards from being exceeded.

New Sources - Particulates

$E = 17.31\, p^{0.16}$ (for P   30 tons/hr)

where E = maximum allowable rate of emissions in lb/hr

P = process weight rate in tons/hr

For a. 50,000 bbl/day SRC plant

$$E = 17.31 \left(\frac{22{,}000 \text{ ton/day}}{24 \text{ hr/day}}\right)^{0.16}$$

$$E = 17.31\,(917)^{0.16} = 51.6 \text{ lb/hr}$$

Table 47. Wyoming Water Quality Standards

Parameter	Concentration Limits		Remarks
Settleable Solids	free from		
Floating Solids	free from		
Toxic Materials	free from		
Turbidity	10 JTU increase		
pH Range	6.5 - 8.5		
Total Gas Pressure	Not to exceed 110% (of atmospheric pressure)		
	Metric	English	
Dissolved Oxygen	6 mg/l	0.3505 grain/gal	Class I water
	5 mg/l	0.2921 grain/gal	Class II water
Oil/Grease	10 mg/l	0.5841 grain/gal	

Temperature

The maximum temperature allowed is 26°C (78°F) for streams supporting cold water fish and 32°C (90°F) for streams supporting warm water fish.

The maximum allowable temperature increase is dependent upon natural water temperature. For streams with maximum natural temperatures of 20°C (68°F) or less the maximum allowable temperature increase is 1.1°C (2 °F) For streams with maximum natural temperatures exceeding 20°C (68°F) the maximum allowable temperature increase is 2.2°C (4°F).

Table 48. EPA National Interim Primary Drinking Water Standards

Constituent	Maximum Concentration	
	Metric (mg/l)	English (grain/gallon)
Arsenic	0.05	0.0029
Barium	1.0	0.0584
Cadmium	0.01	5.84×10^{-4}
Chromium	0.05	2.92
Lead	0.05	0.0029
Mercury	0.002	1.17×10^{-4}
Nitrate (as N)	10	0.5841
Selenium	0.01	5.84×10^{-4}
Silver	0.05	0.0029

	Temperature (°C)	Concentration (mg/l)	Temperature (°F)	Concentration (grain/gal)
Fluorine	12.1 & below	2.4	53.7 & below	0.1402
	12.2 - 14.6	2.2	53.8 - 58.3	0.1285
	14.7 - 17.7	2.0	58.4 - 63.8	0.1168
	17.8 - 21.4	1.8	63.9 - 70.6	0.1051
	21.5 - 26.2	1.6	70.7 - 79.2	0.0935
	26.3 - 32.5	1.4	79.3 - 90.5	0.0818